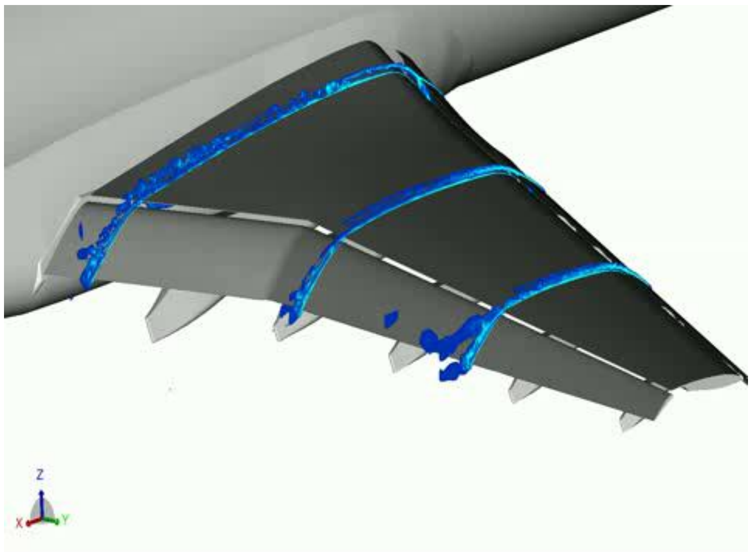


PowerFLOW Analysis DLR-F11 Configuration

HiLiftPW-2

San Diego – 2013

Benedikt König
André Ribero
Ehab Fares
Swen Nölting

Exa

Overview

- Introduction Lattice Boltzmann Method
- Grid Convergence Study
- Reynolds Number Study
  - *Impact of Laminar/Turbulent Transition*
- General Flow Analysis
- Comparison Config 4 vs Config 5

Overview

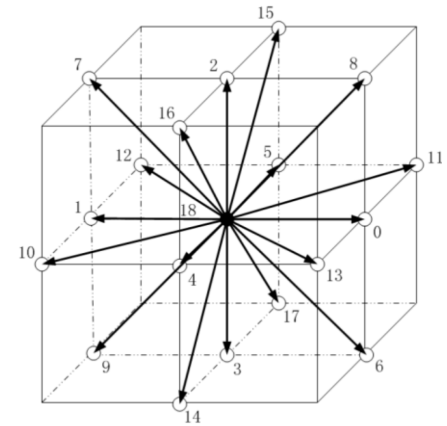
Simulations

Description	Low Reynolds	High Reynolds
Case 1	-	16° (c/m/f)
Case 2 a/b	19°	-
Case 3 a/b	0°-22°	0°-23.5°
Case 3 a/b with Transition	16°, 19°	16°, 19°

Lattice Boltzmann Method

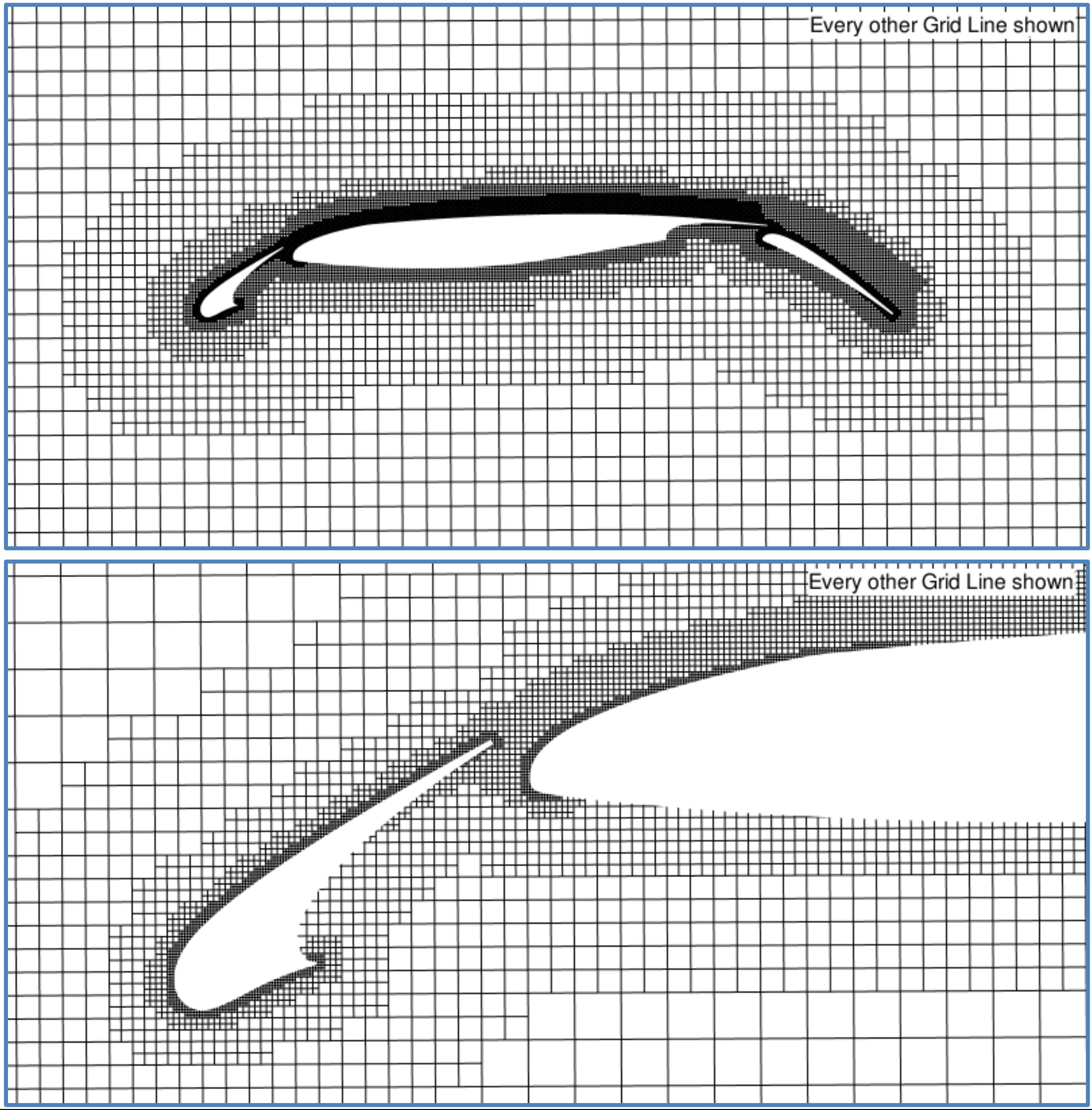
Lattice Boltzmann Method

- Simulations performed with Lattice Boltzmann based solver PowerFLOW 5.0 beta
  - *D3Q19 LBM*
    - Cubic cells (Voxels)
    - Surface elements (Surfels)
  - *Fully transient*
  - *Turbulence Model: LBM-VLES*
    - Modified RNG *k*-*ε* model for unresolved scales
    - Swirl model
    - Extended wall model
  - *LTT Model*
    - Automatically determines transition locations



Lattice Boltzmann Method
Grid Scheme

- Cartesian Grid
- Voxel/Surfel concept with cut cells
  → no surface fitted grid required
- Automatic and robust grid generation process



Lattice Boltzmann Method
Case Setups

- Grid Refinement Study
  - *Refinement ratio 1.4*

	Voxels $[10^6]$	Resolution		Refine Ratio	Number Total Voxels Ratio	Runtime per 0.1sec(*)
		Space [mm]	Time [sec]			
Coarse	90.3	0.23	6.0×10^{-7}	1.4	2.26	0.6d
Medium	214.6	0.16	4.2×10^{-7}	1.4	2.37	1.6d
Fine	545.7	0.11	3.0×10^{-7}	1.4	2.54	4.2d

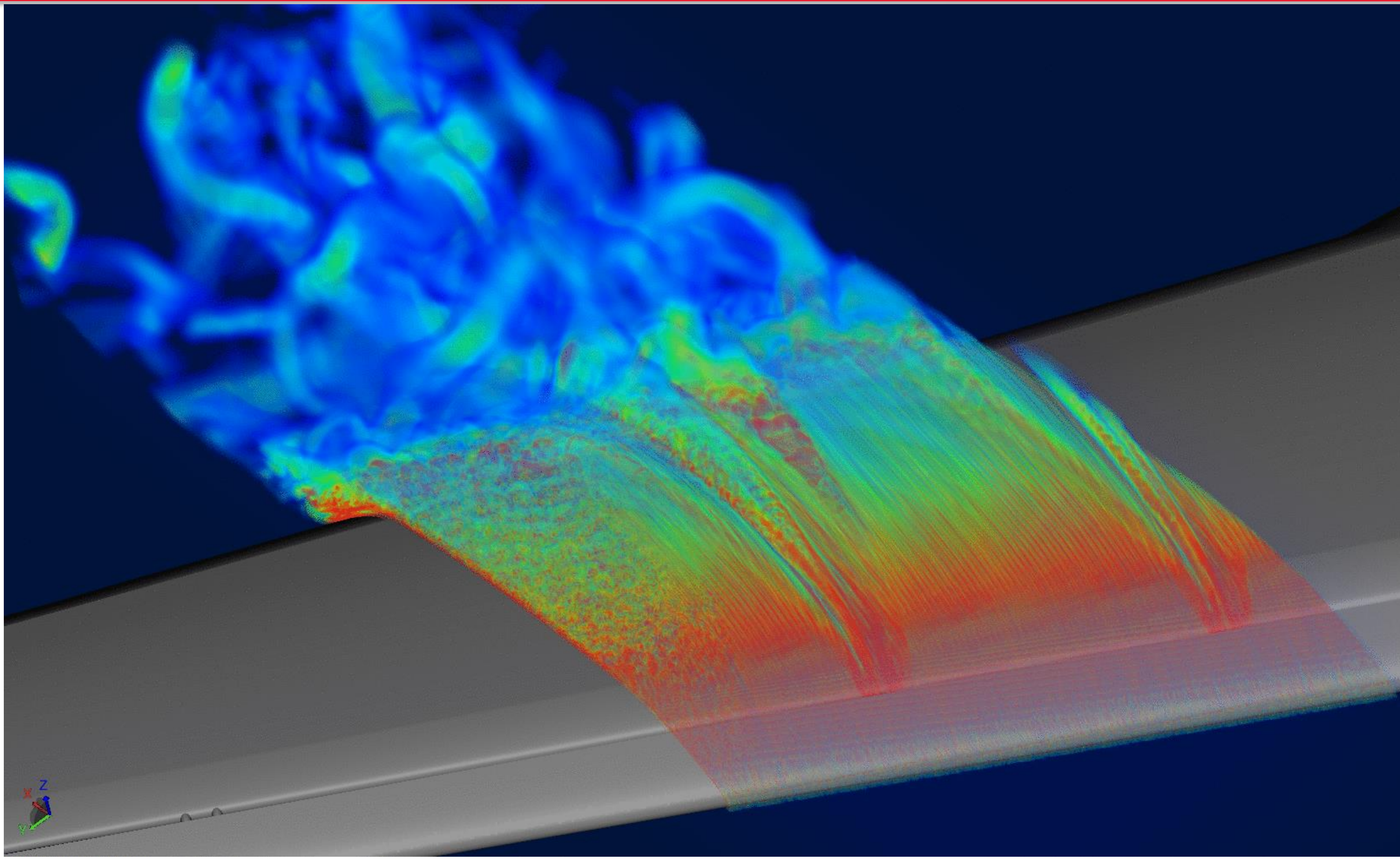
(*) simulated physical time on 560 cores Intel Sandybridge 2.7GHz

- Reynolds Number Study
  - *medium-equivalent grid used*

Voxels	Resolution		Runtime per 0.1sec(*)
	Space [mm]	Time [sec]	
280×10^6	0.14	3.9×10^{-7}	1.9d

Exa

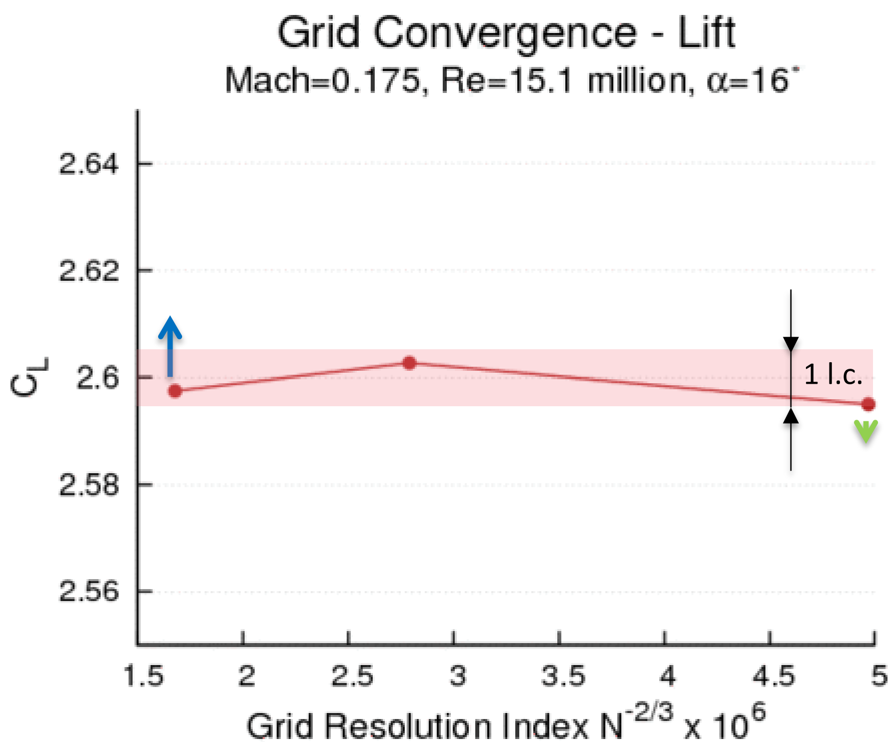
Lattice Boltzmann Method
Example – Vorticity

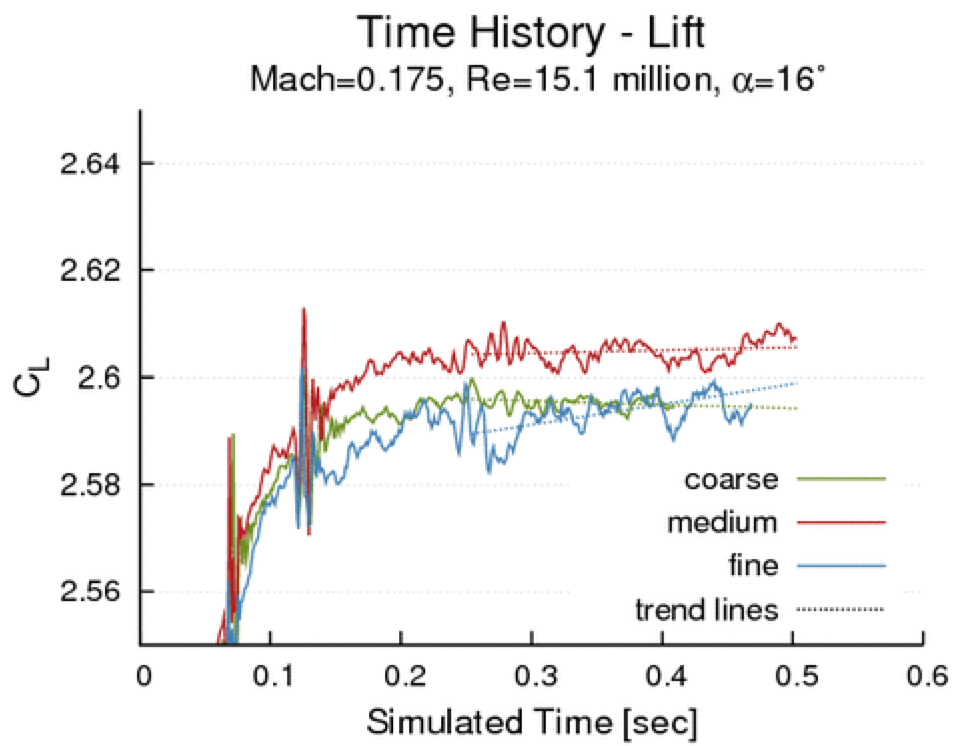


Gird Convergence Study

Grid Convergence Study
Lift

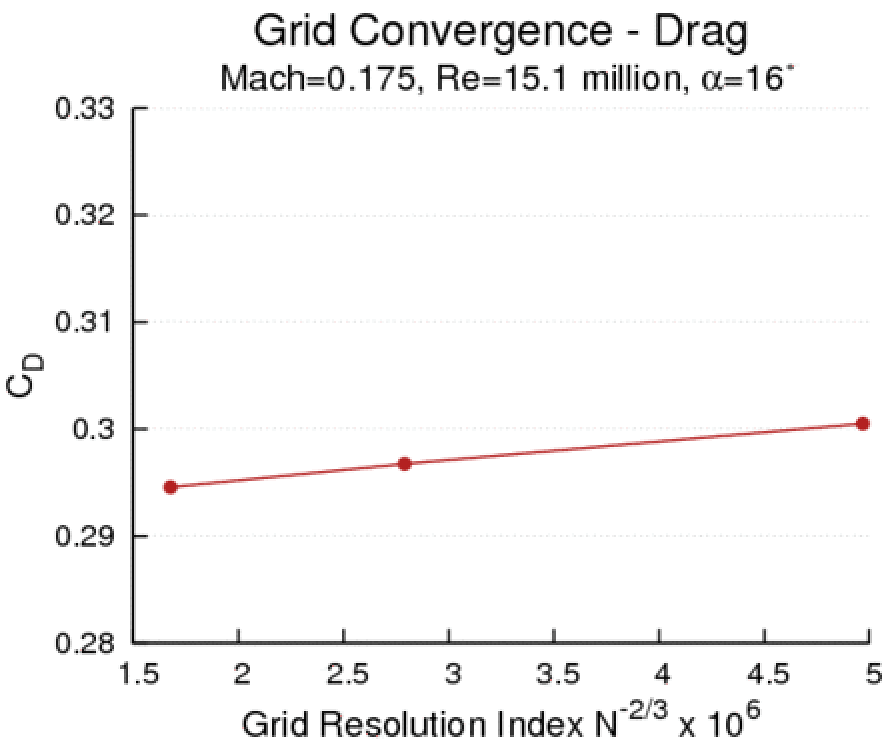
- Asymptotic convergence not yet reached
- Trend lines (for t > 0.25 sec) indicate that for longer runtimes picture will change

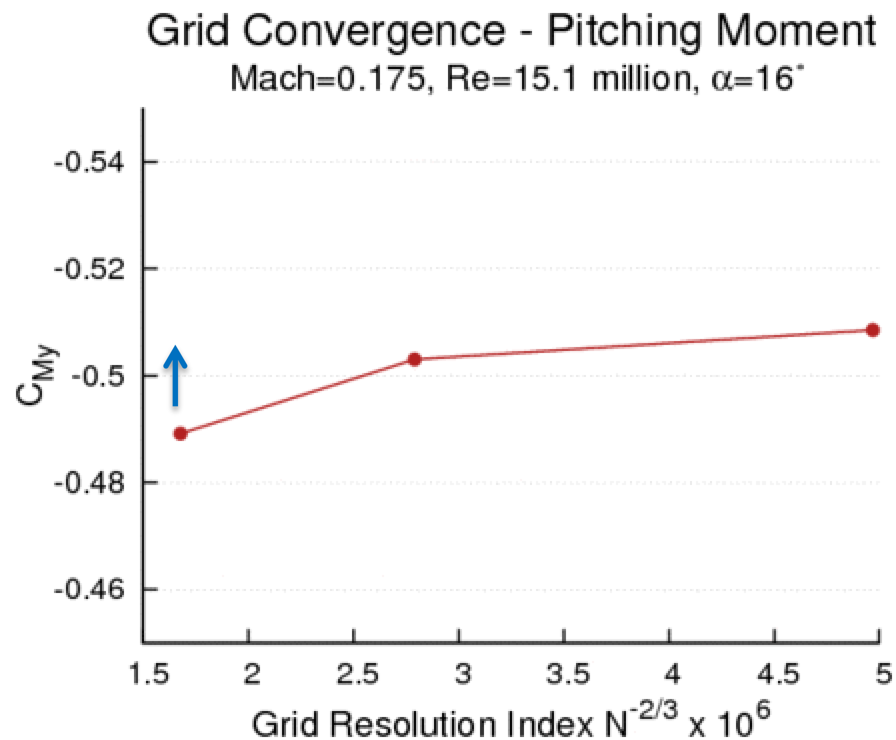




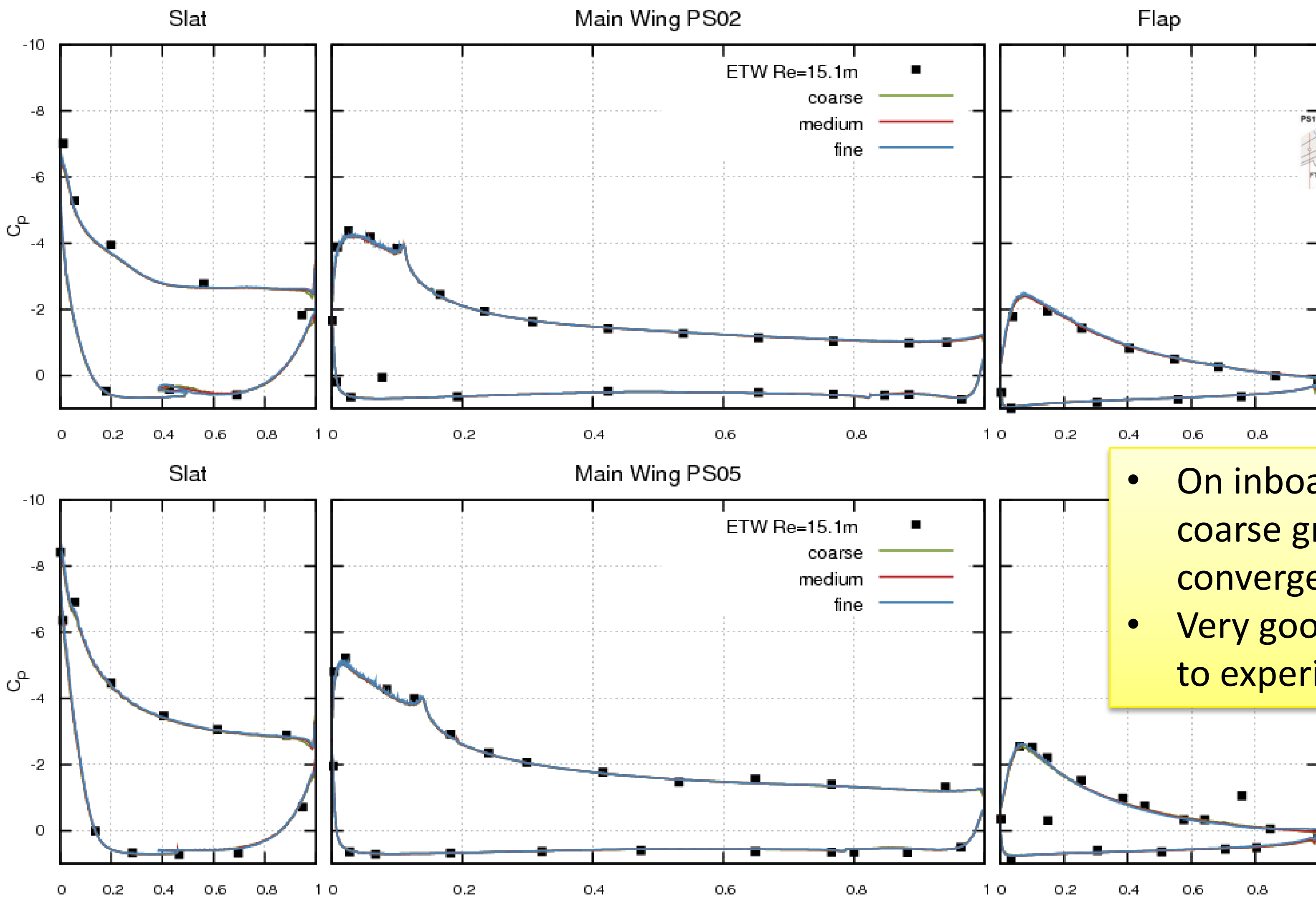
Grid Convergence Study
Drag and Pitching Moment

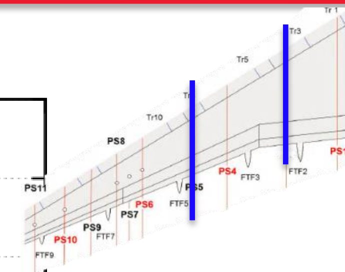
- Asymptotic convergence achieved for drag
- Pitching moment similar to lift, still showing slow trends





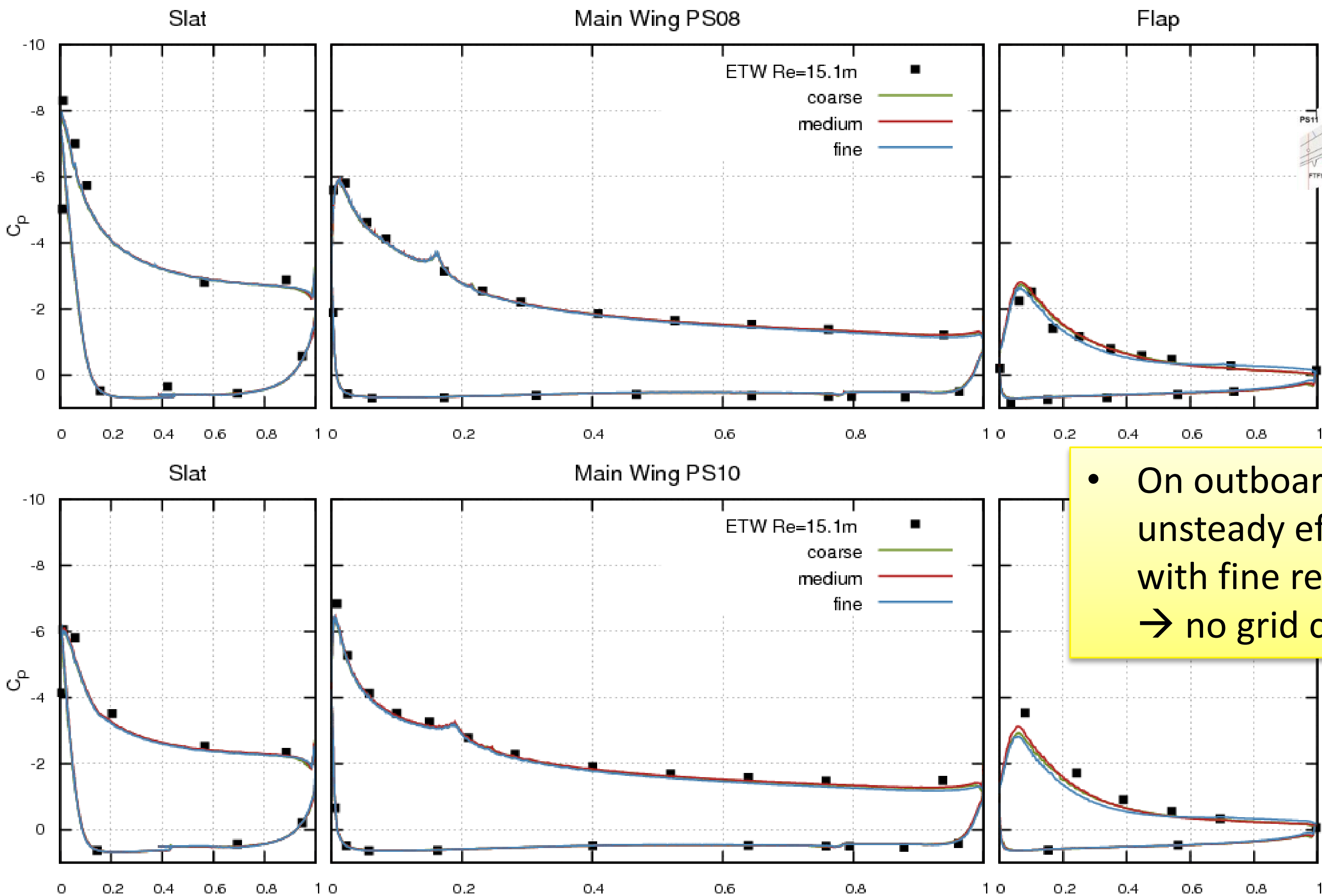
Grid Convergence Study
Cp-Distributions

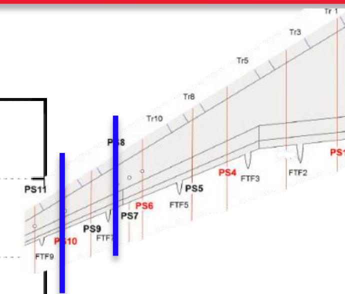




- On inboard wing even coarse grid delivers converged solutions
- Very good agreement to experimental data

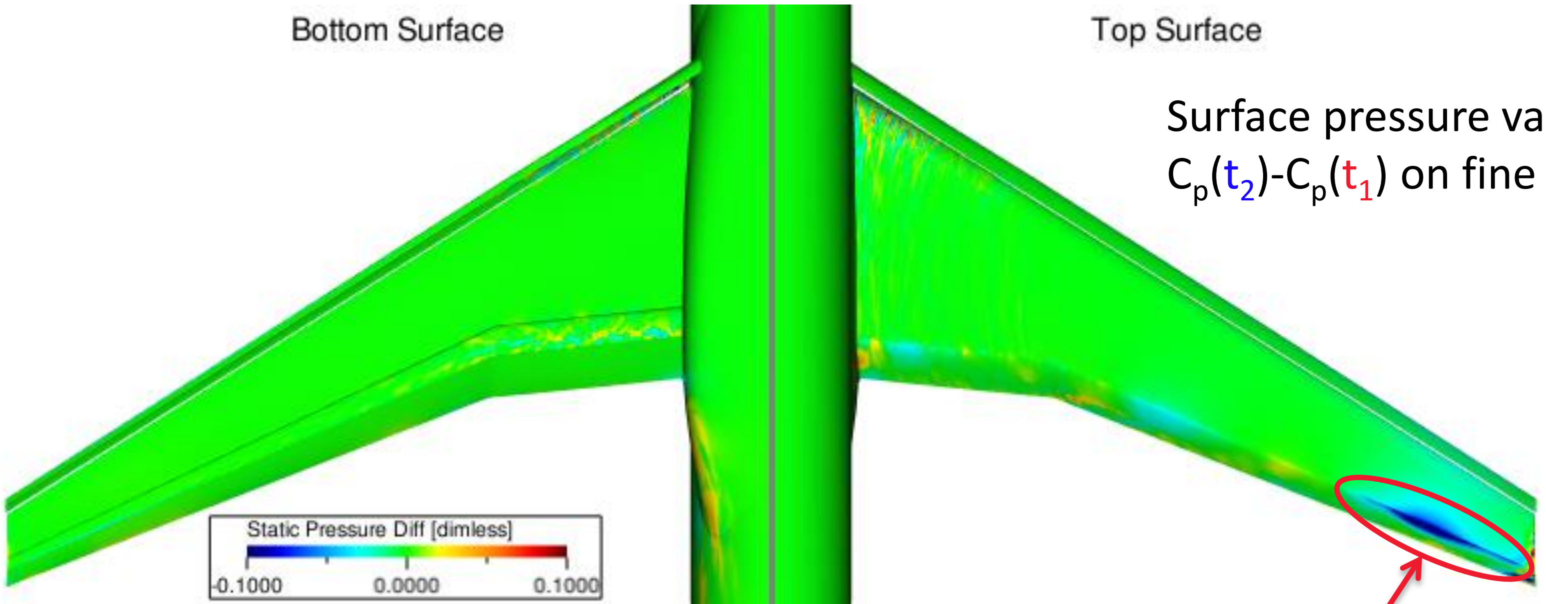
Grid Convergence Study
Cp-Distributions



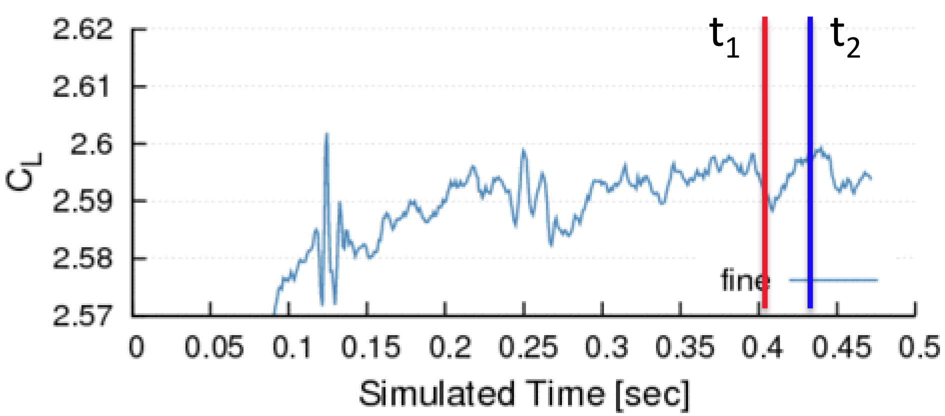


- On outboard wing some unsteady effects occur with fine resolution
  → no grid convergence

Grid Convergence Study
Unsteadiness at Higher Resolution



Surface pressure variation
$C_p(t_2)$-$C_p(t_1)$ on fine grid

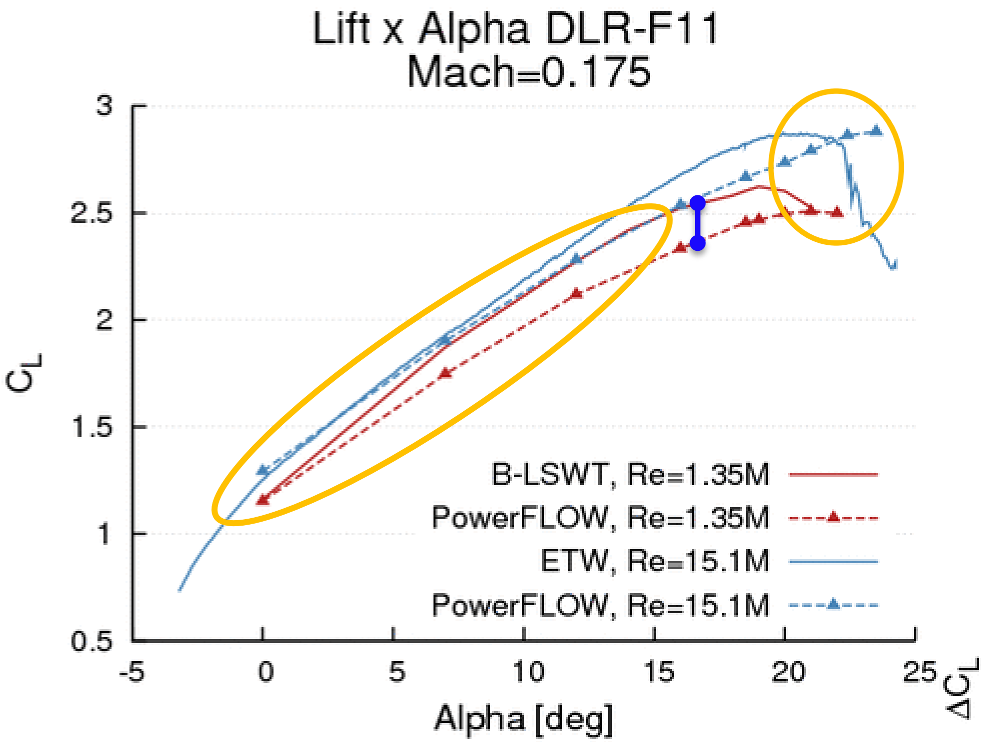


Significant unsteadiness on fine grid

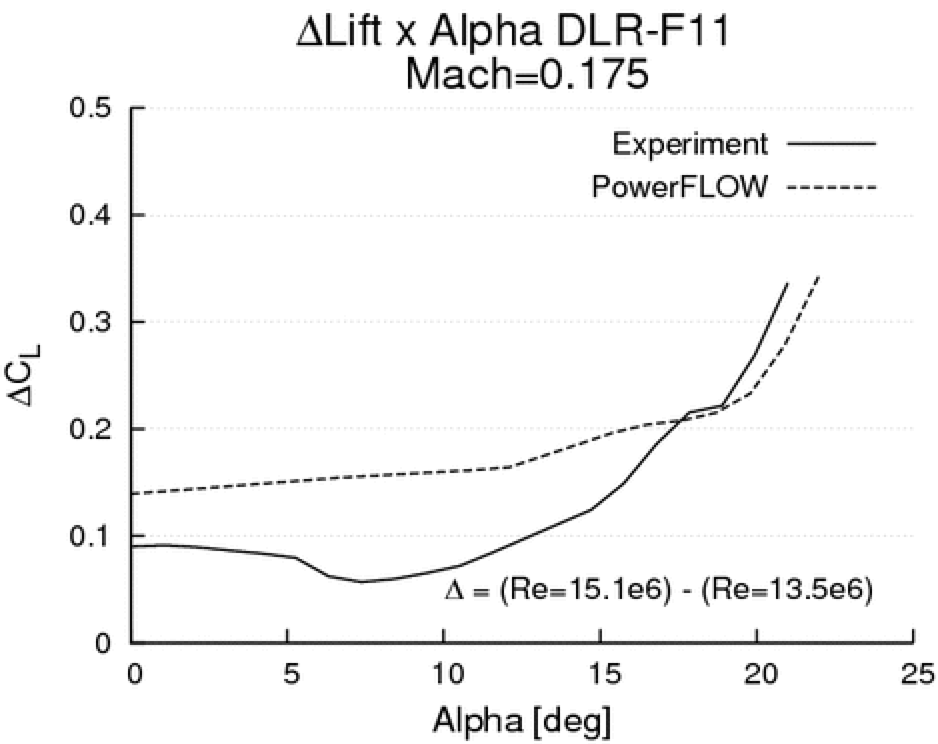
Reynolds Number Study
Config 5

Results

Reynolds Number Study
Lift Polar

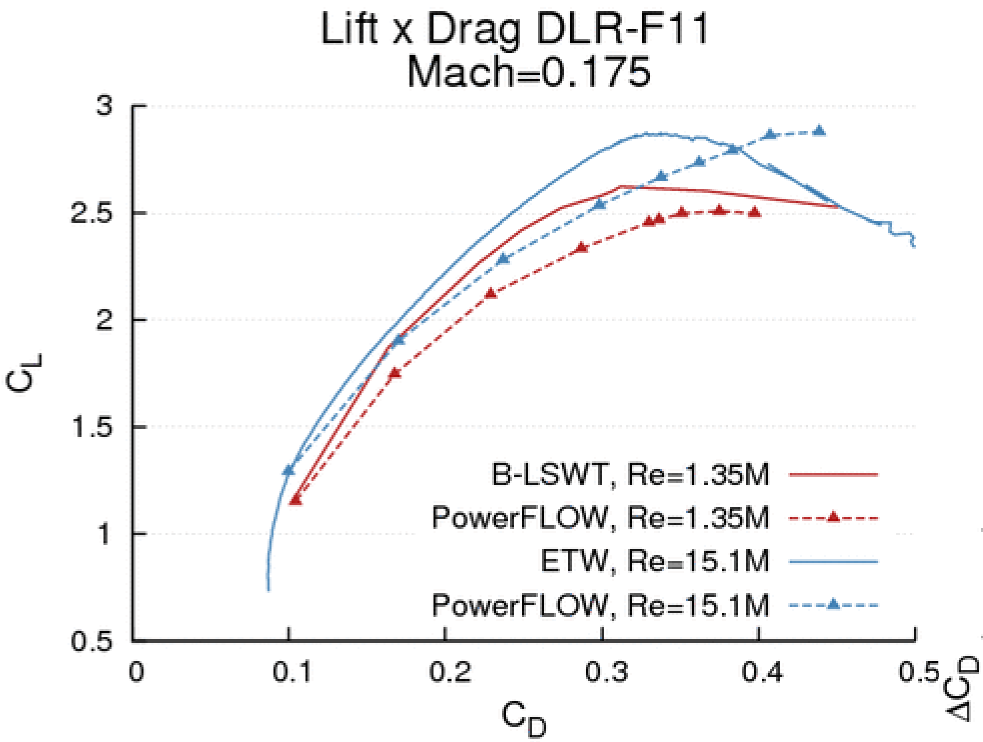


- Reynolds trends captured well except for polar shape difference between low and high Reynolds numbers in WT

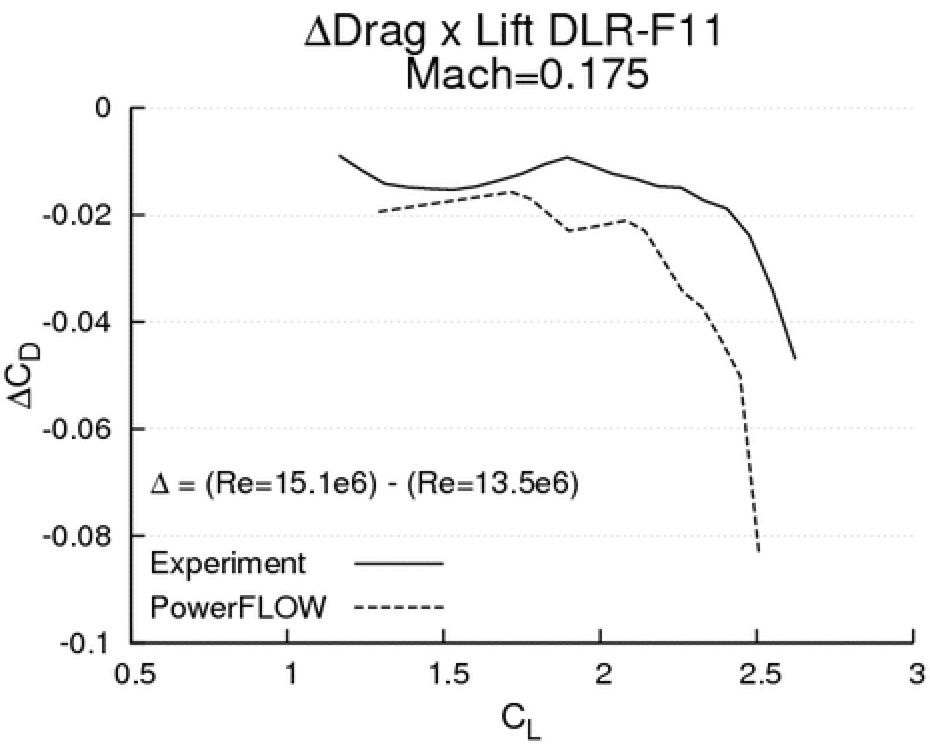


1. CL under-predicted → laminar/turbulent
2. Lift slope under-predicted and variation not captured → effect of half-model testing? (compare peniche effect)
3. Delayed stall (due to under-predicted lift?)

Reynolds Number Study
Drag Polar

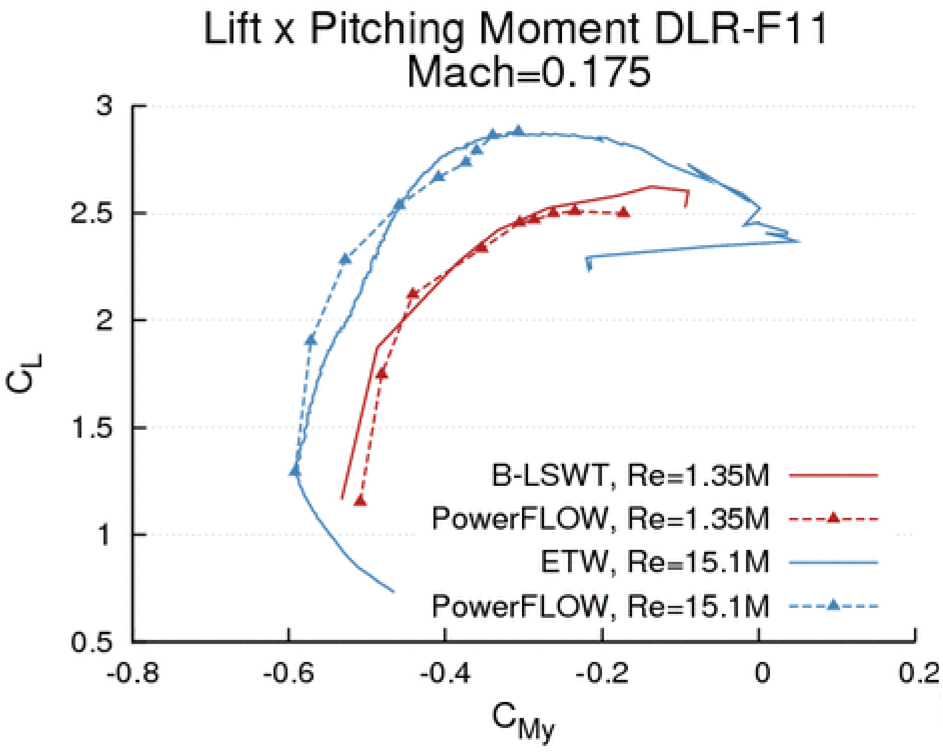


- Reynolds trend for drag well captured

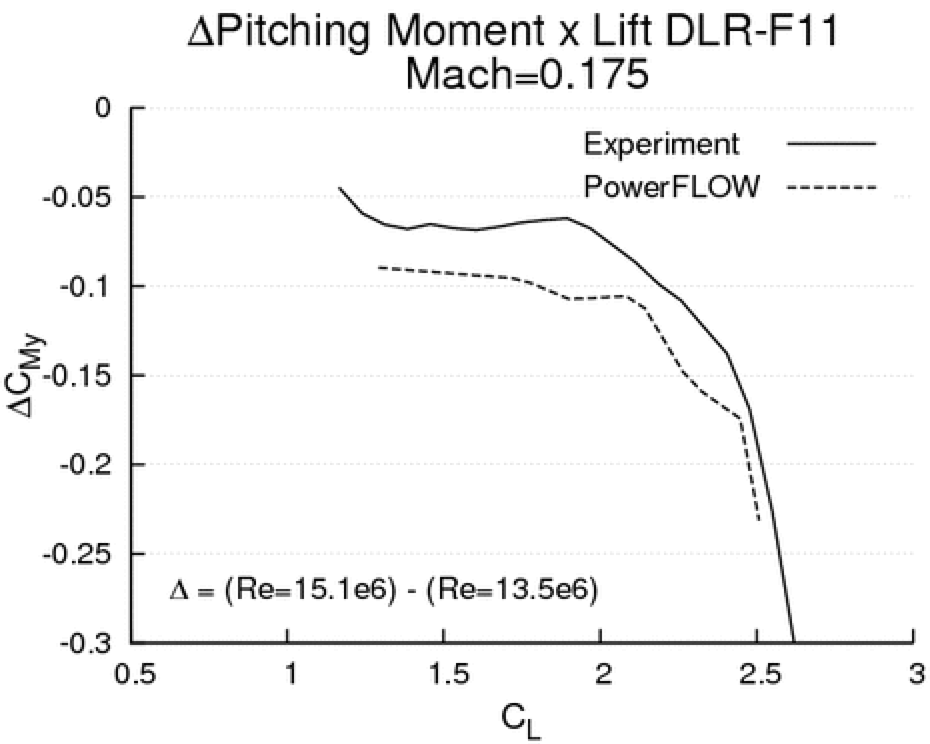


1. Very good agreement at low CL
2. Over-predicting drag around Clmax (partly due to laminar/turbulent transition)

Reynolds Number Study
Pitching Moment Polar

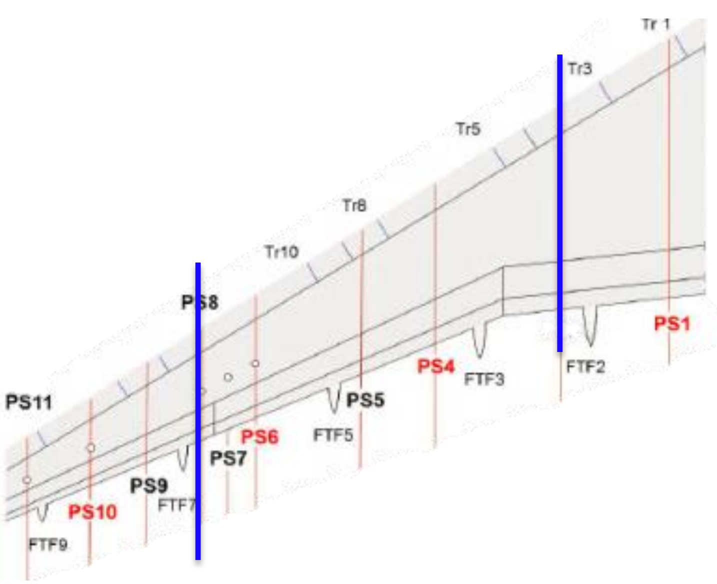


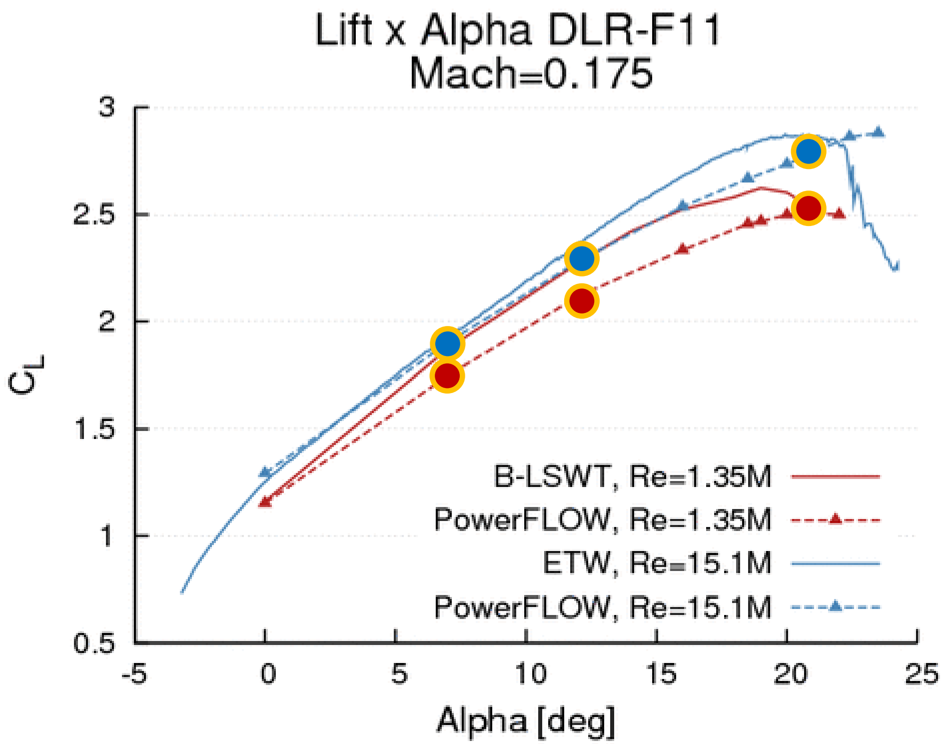
- Very good agreement both absolute and for Reynolds trend



Reynolds Number Study
Pressure Distributions

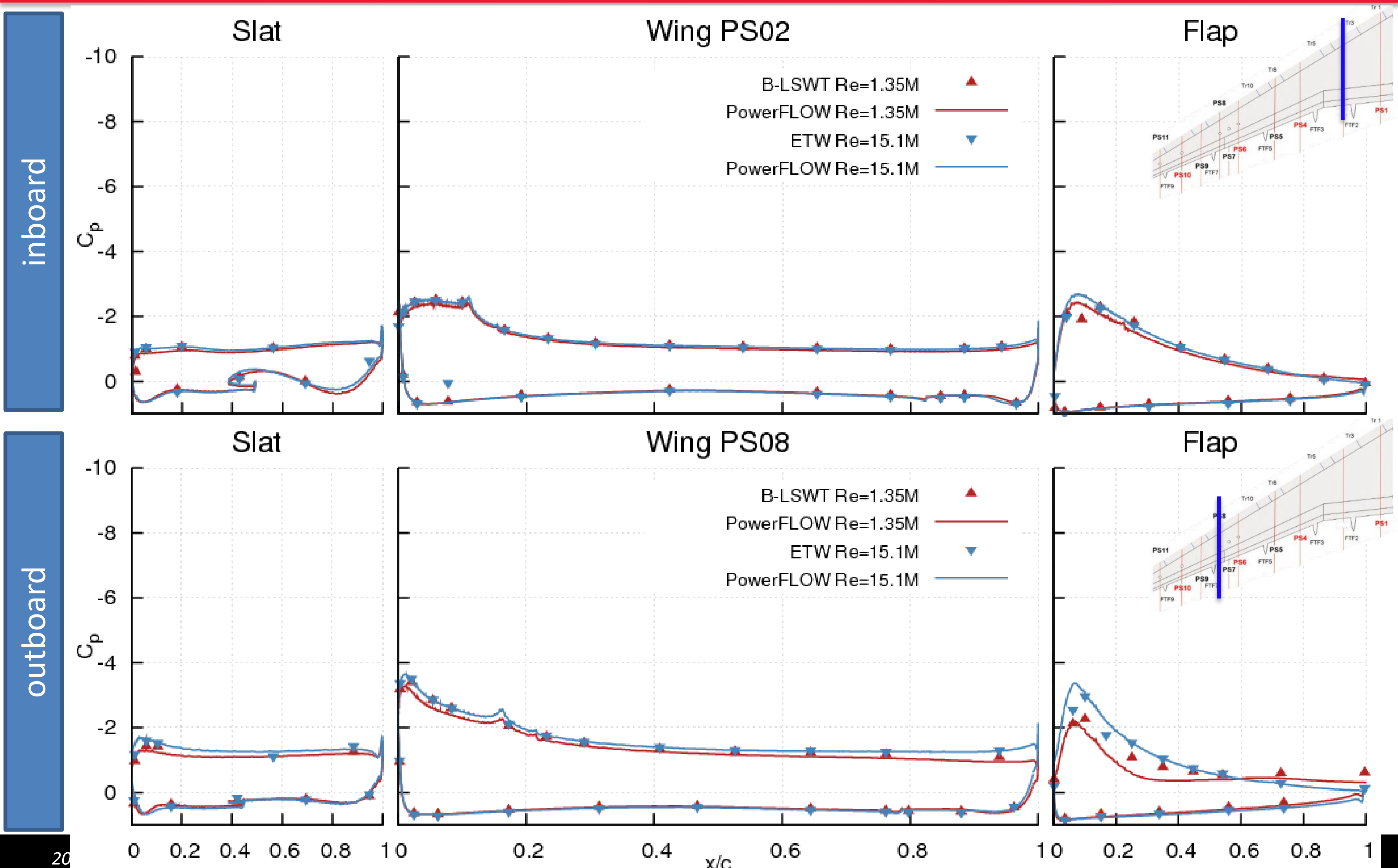
- Pressure distributions at Alpha= 7°,16°,21° are shown
- Inboard (PS02) and outboard (PS08) sections



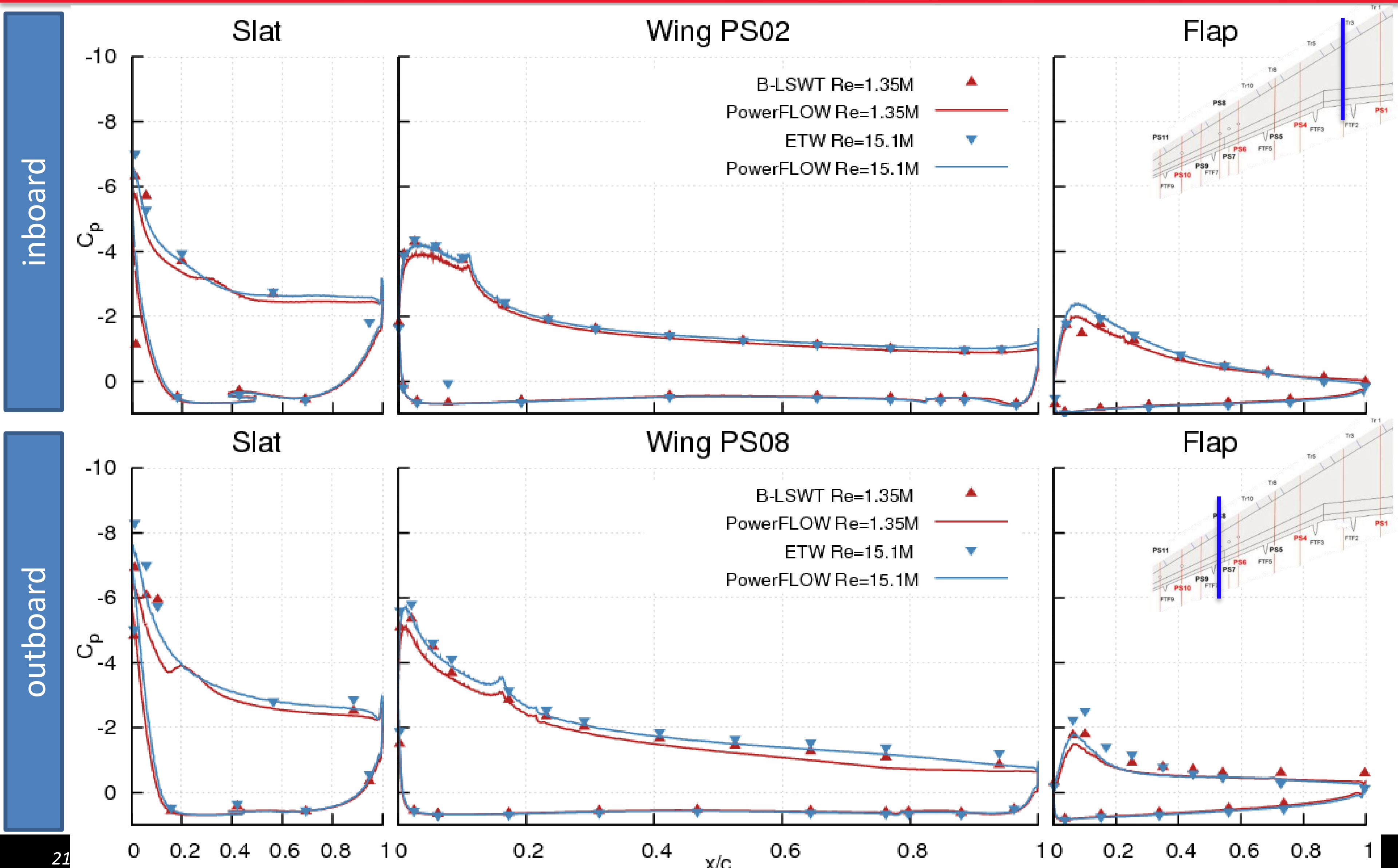


Reynolds Number Study

Pressure Distributions – Alpha = 7deg

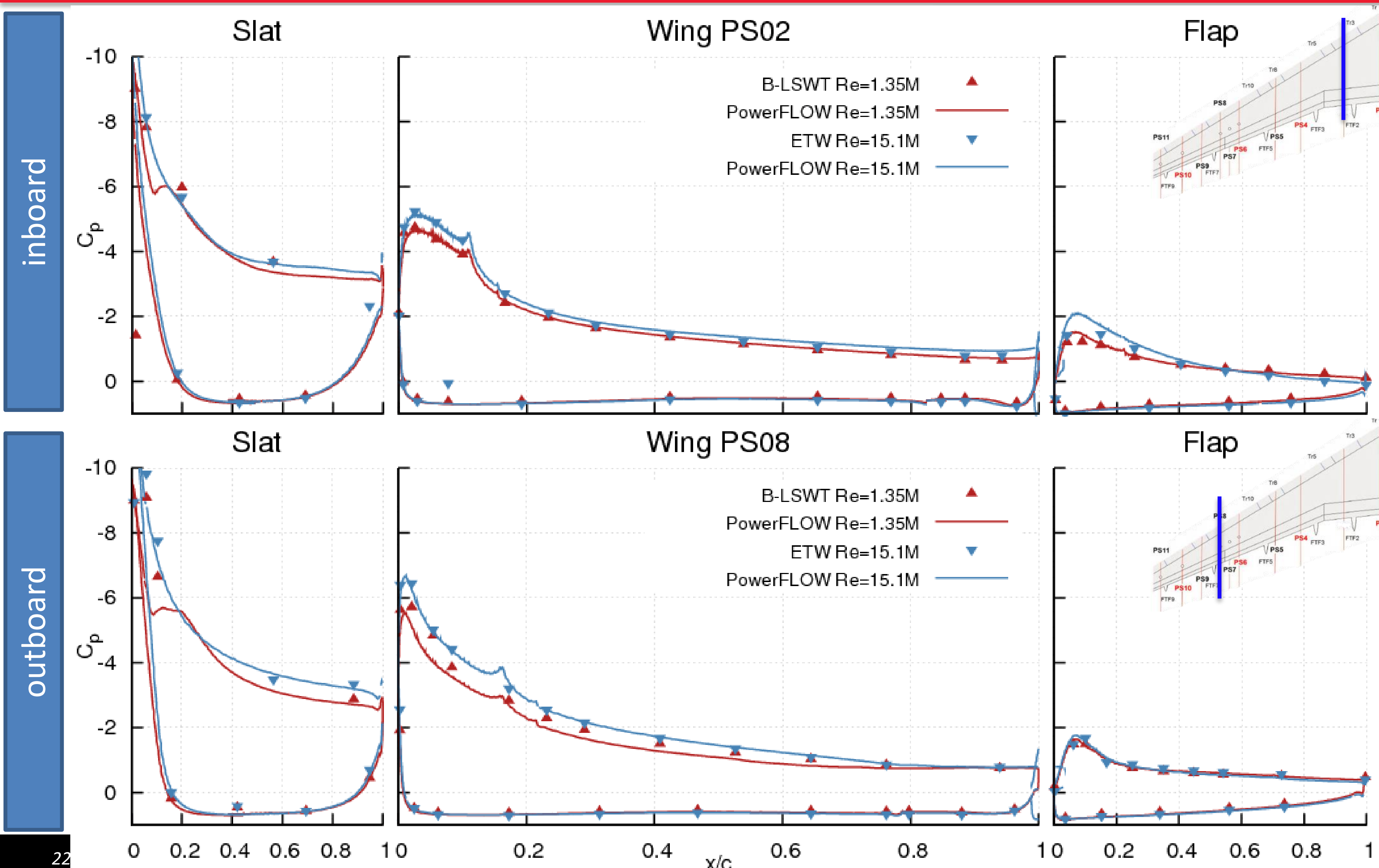


Reynolds Number Study
Pressure Distributions – Alpha = 16deg



Reynolds Number Study

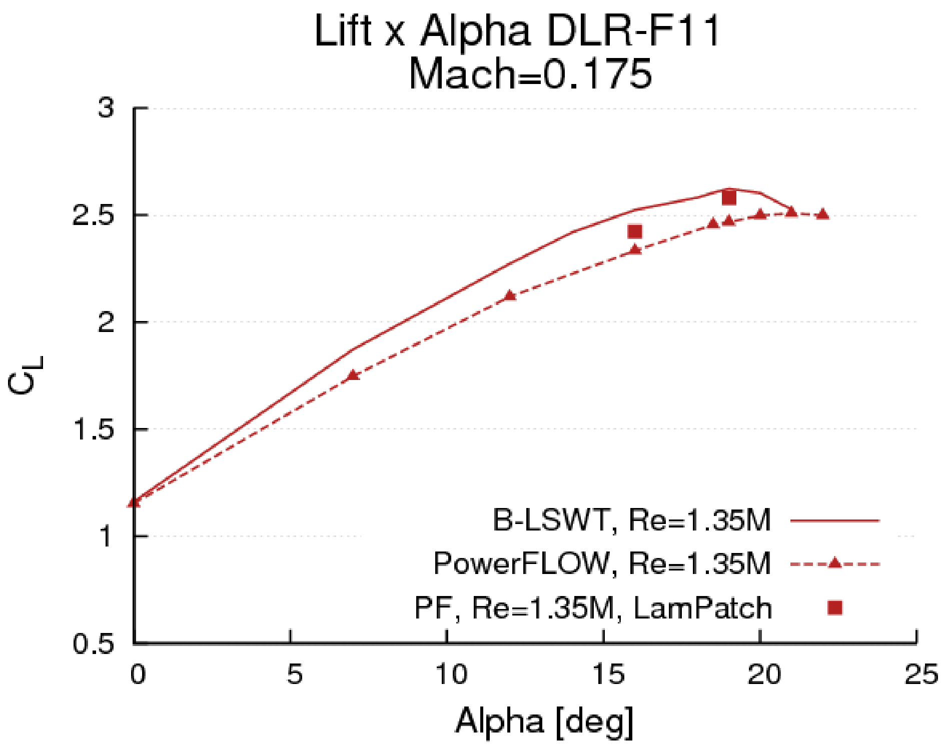
Pressure Distributions – Alpha = 21deg

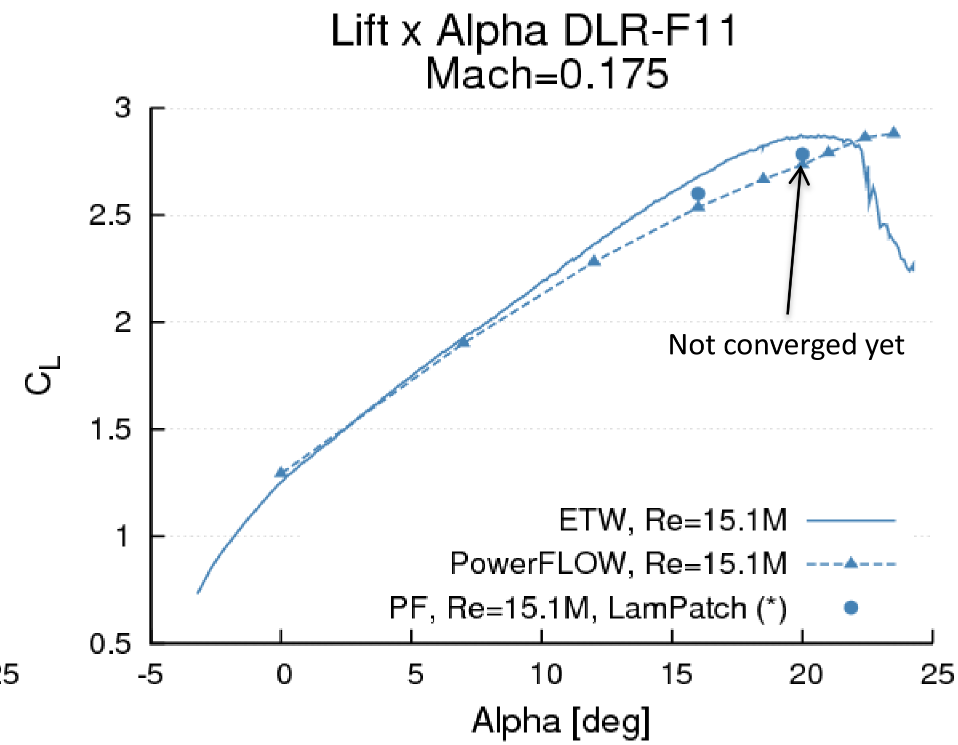


Reynolds Number Study
with Laminar/Turbulent Transition

Results

Transition Study
Pressure Distributions – Alpha = 16deg

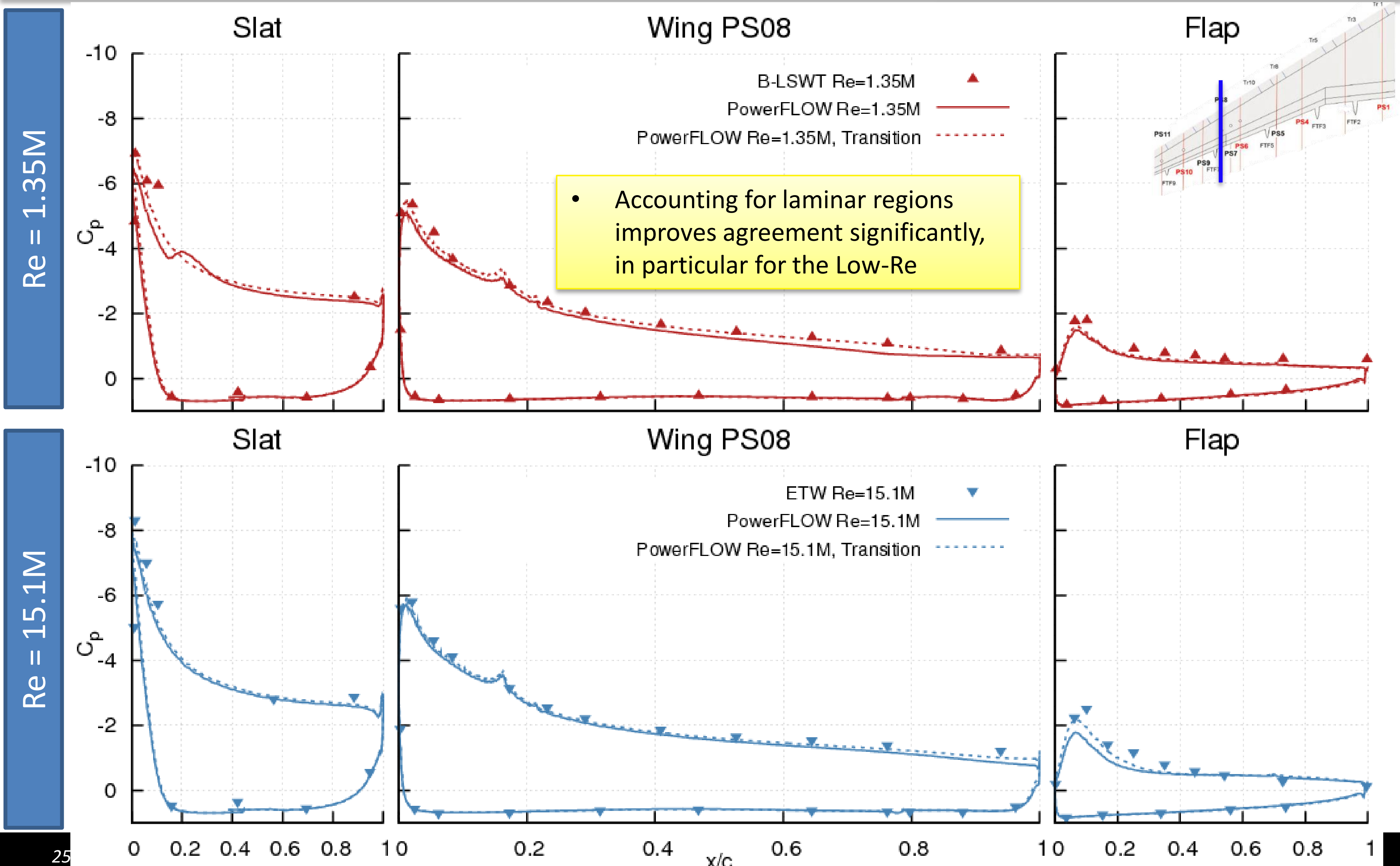




- Inclusion of laminar/turbulent transition significantly improves CL levels, especially at low Reynolds number
- Work in progress

Transition Study

Pressure Distributions – Alpha = 16deg



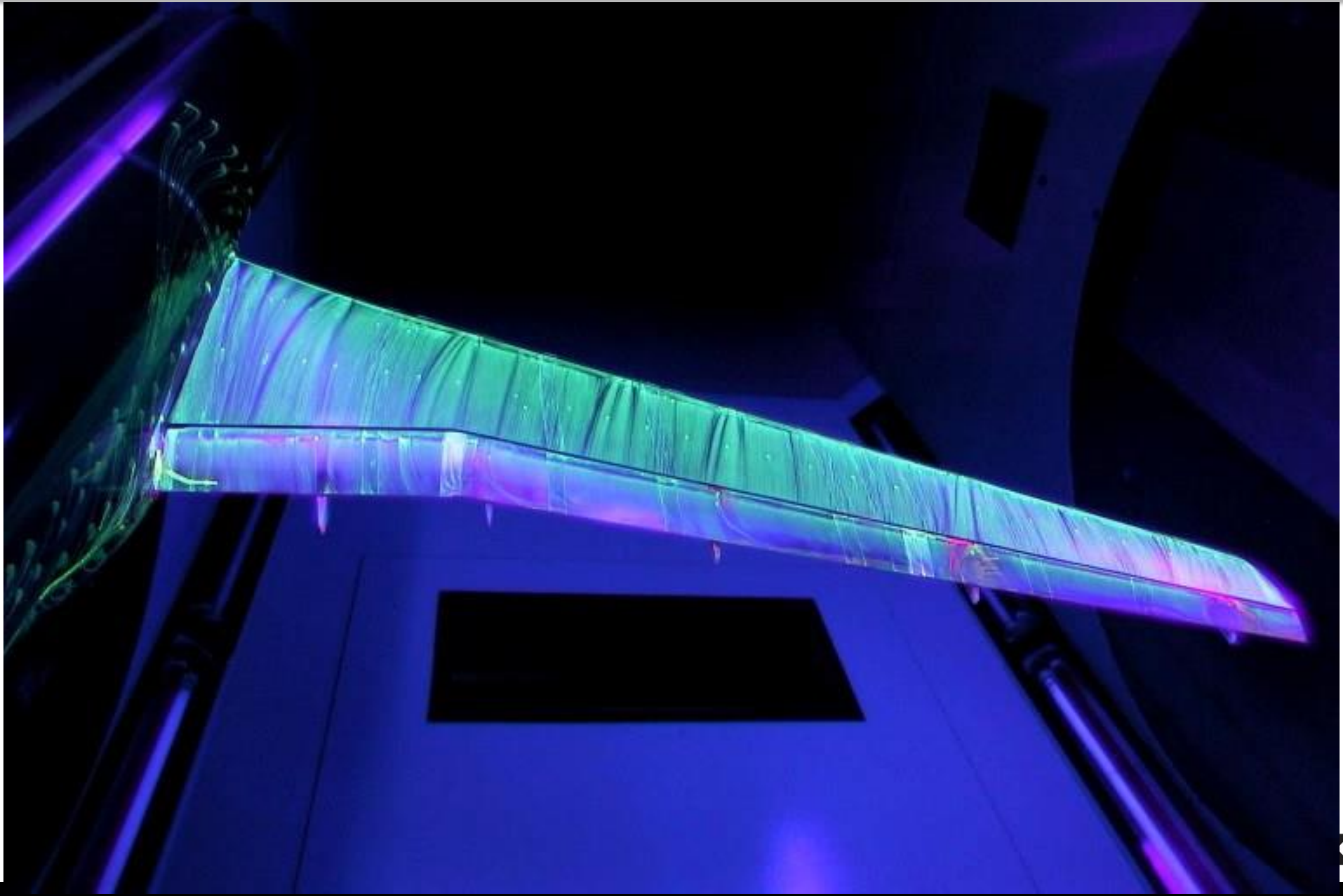
- Accounting for laminar regions improves agreement significantly, in particular for the Low-Re

Flow Analysis and Comparison to Experiment

Low Reynolds Number

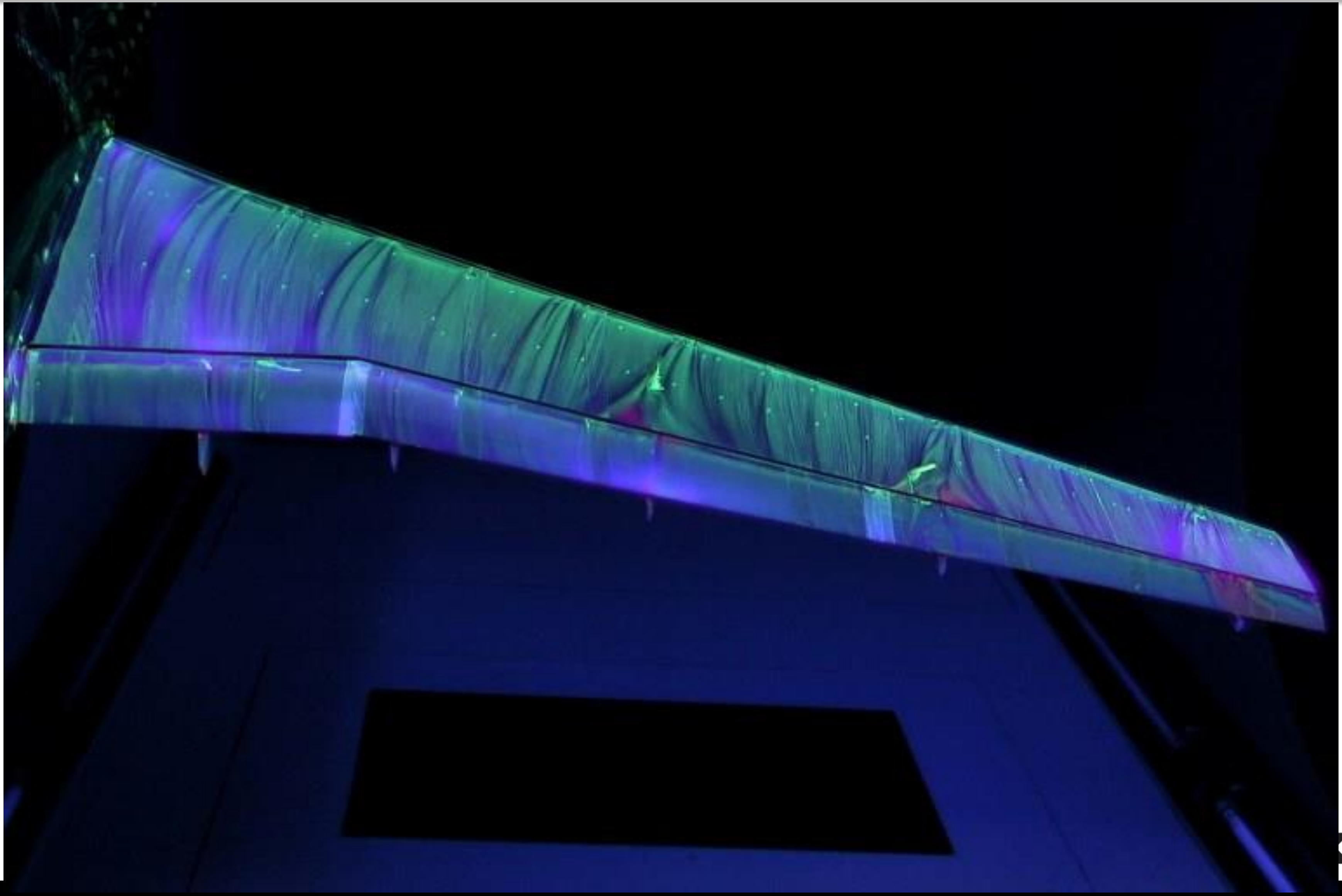
Flow Visualization

Surface Flow – Alpha = 7deg

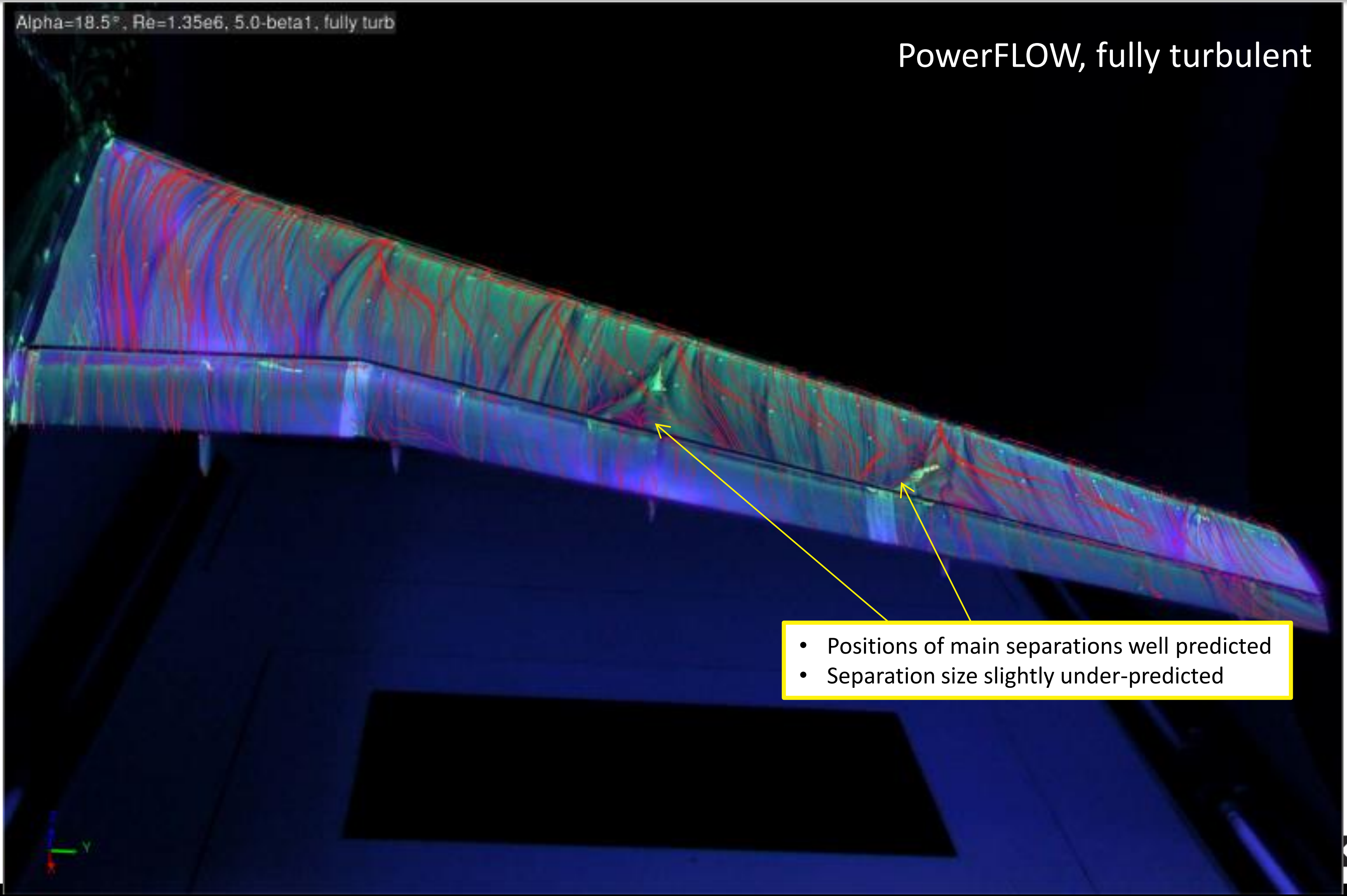


Flow Visualization
Surface Flow – Alpha = 7deg

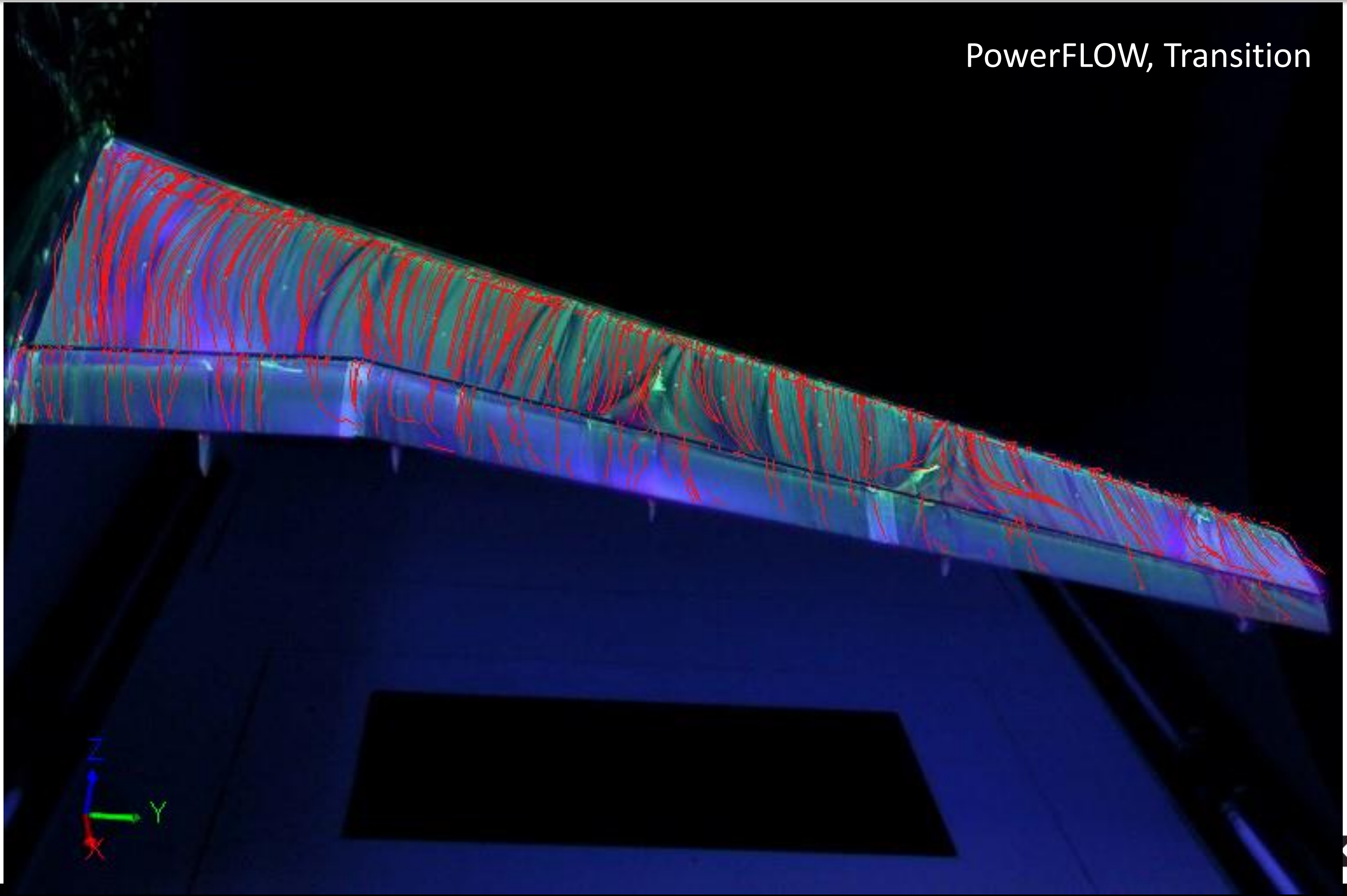
Flow Visualization
Surface Flow – Alpha = 18.5deg



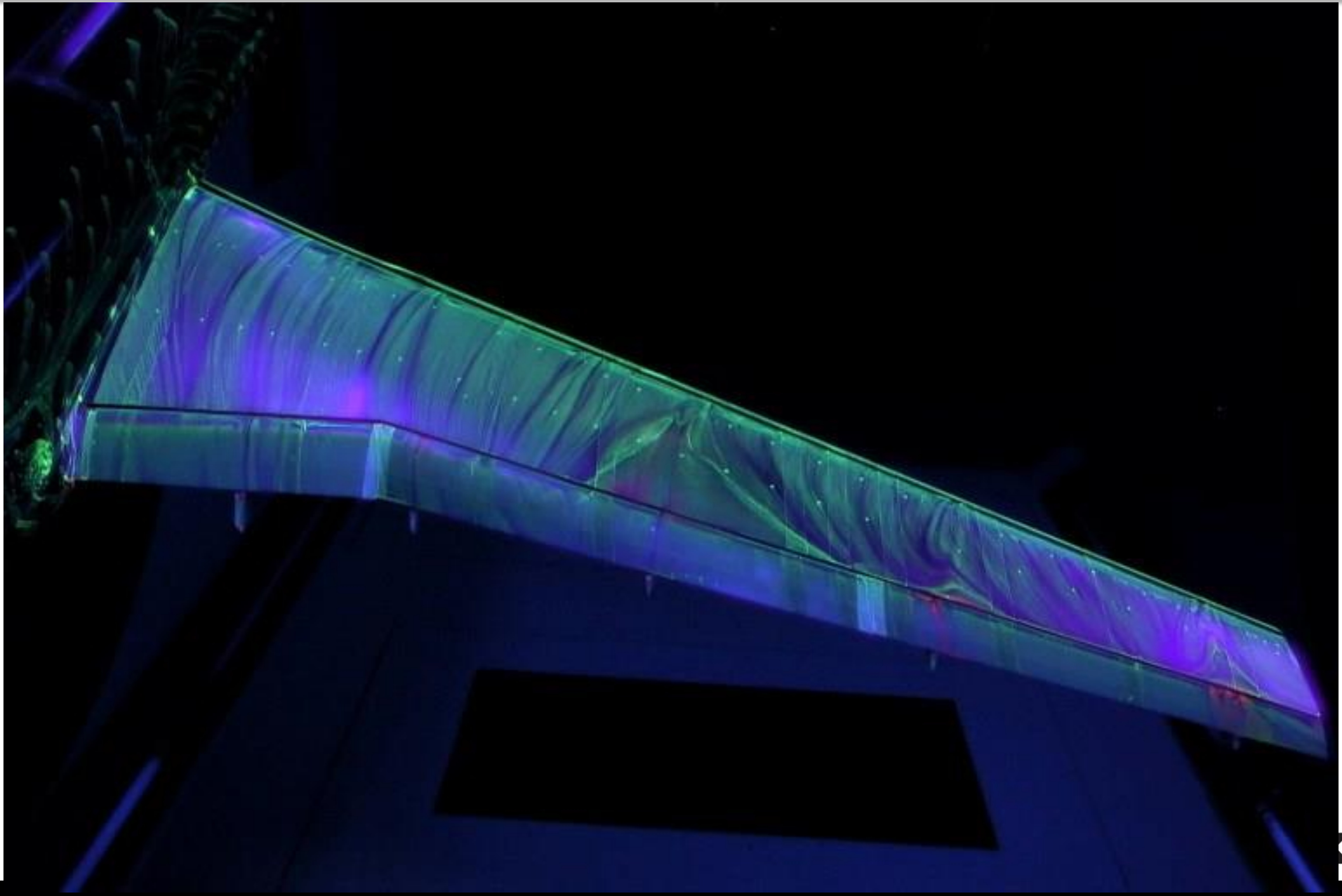
Flow Visualization
Surface Flow – Alpha = 18.5deg



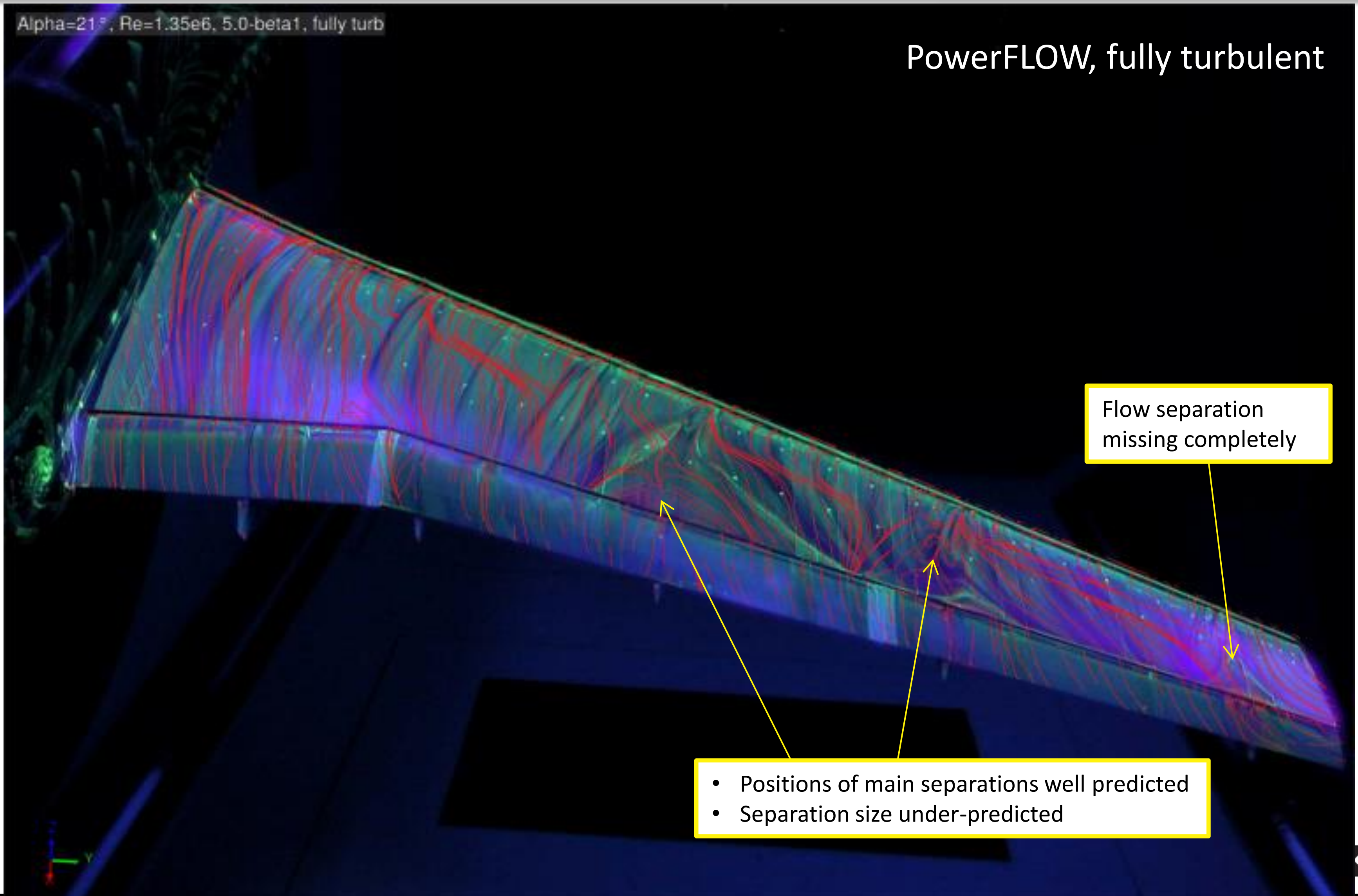
Flow Visualization
Surface Flow – Alpha = 18.5deg



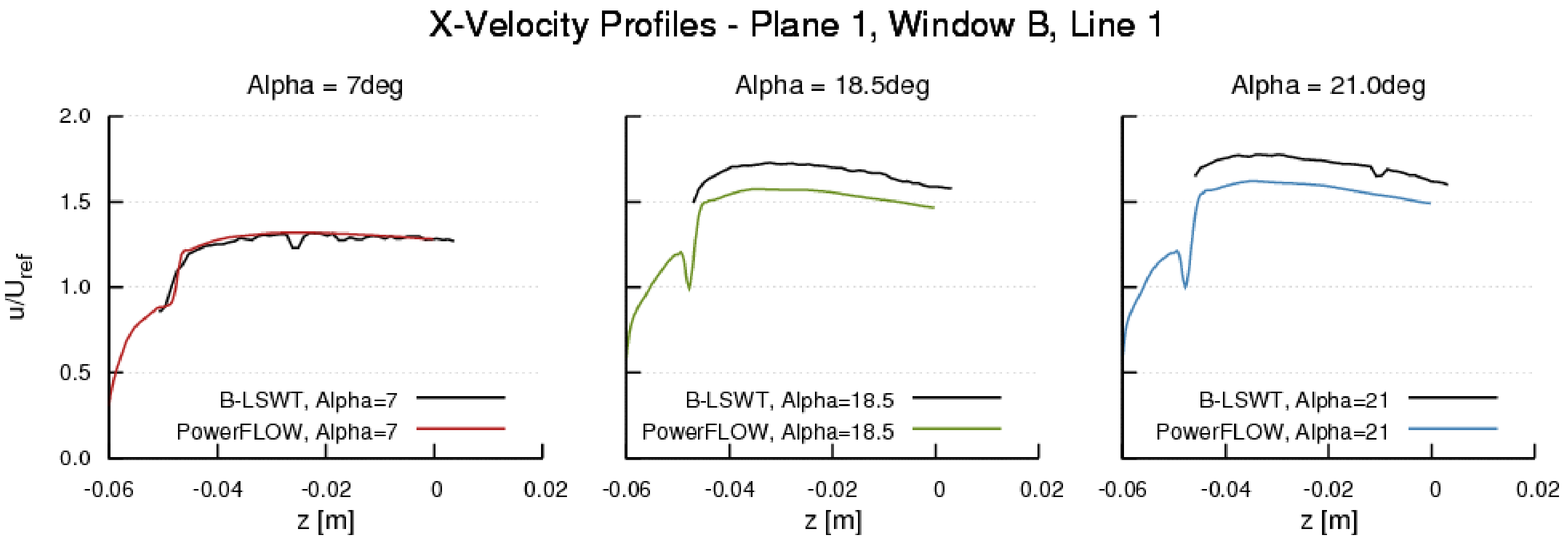
Flow Visualization
Surface Flow – Alpha = 21deg

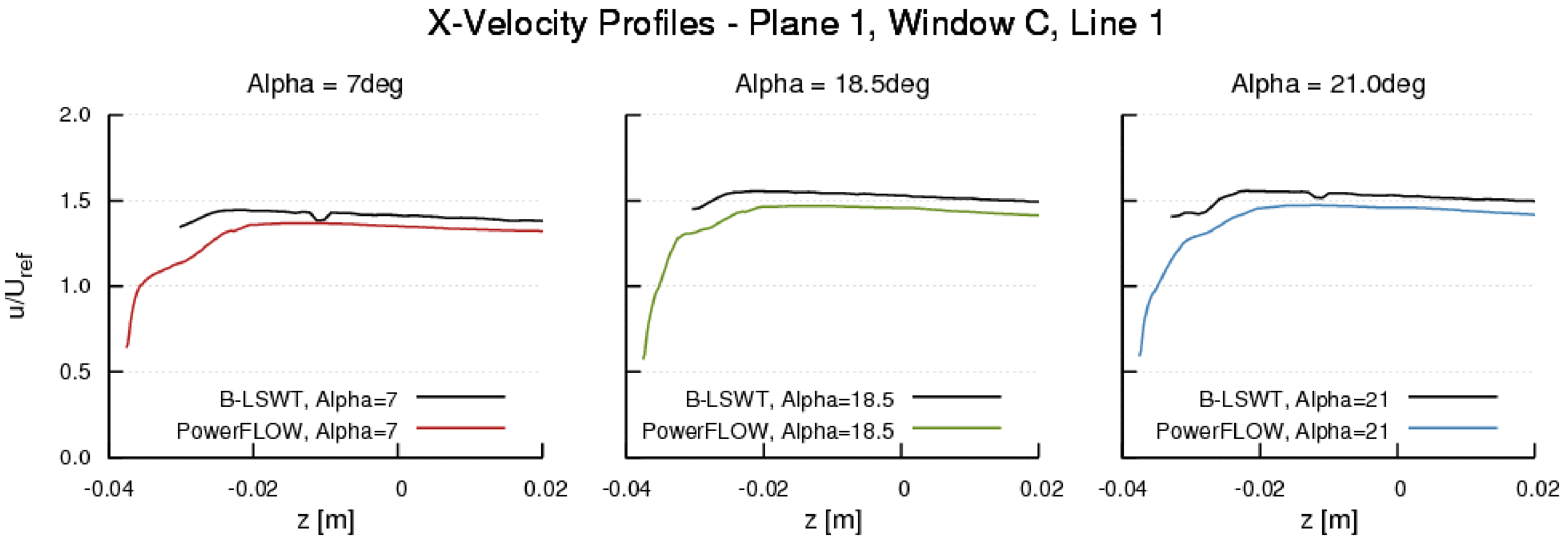


Flow Visualization
Surface Flow – Alpha = 21deg, fully turbulent

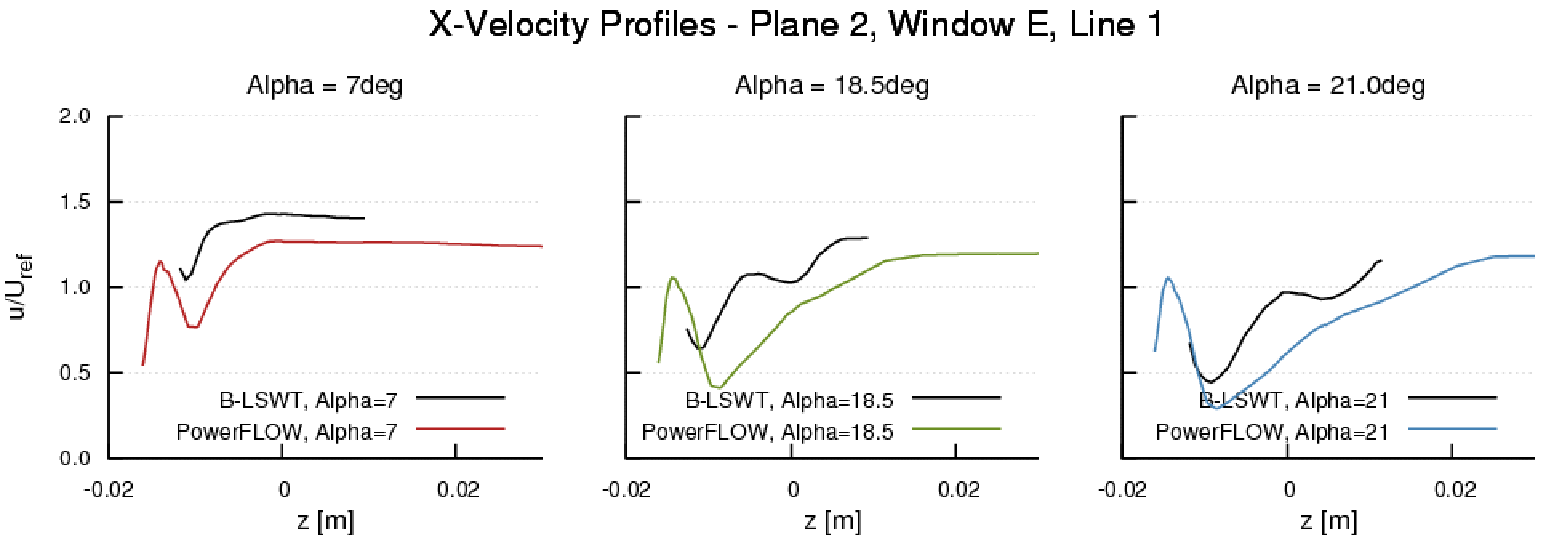


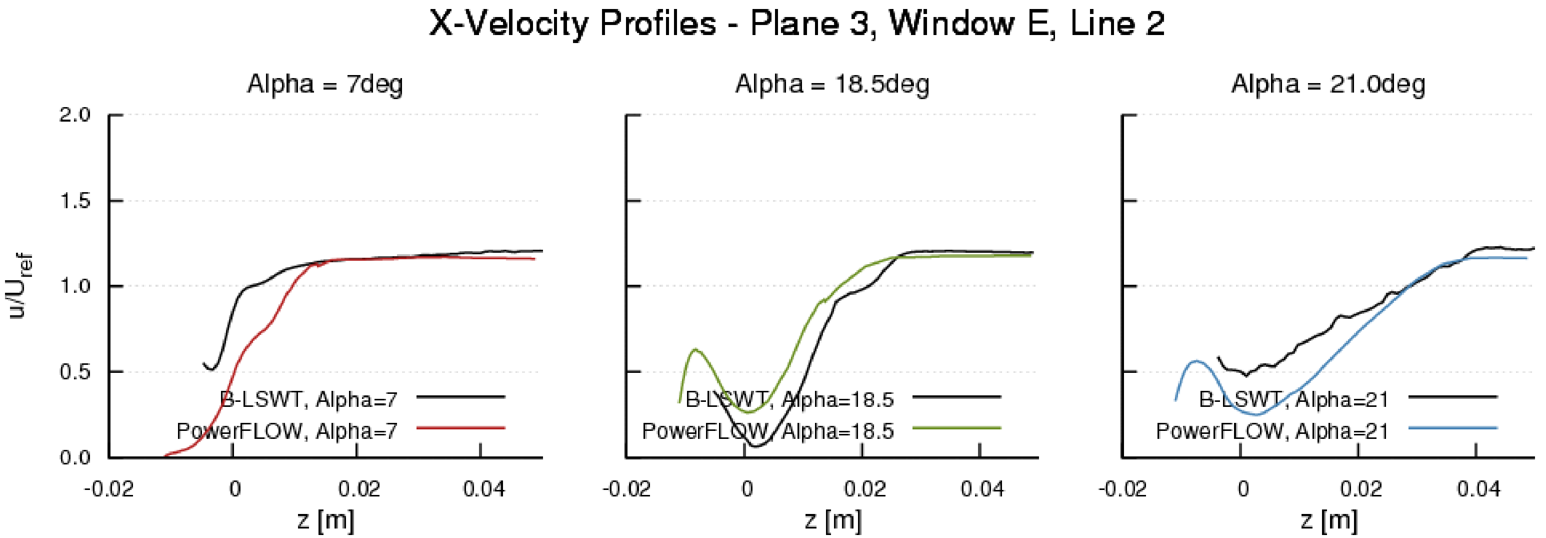
Velocity Profiles
Inboard Wing





Velocity Profiles
Outboard Wing – Flap

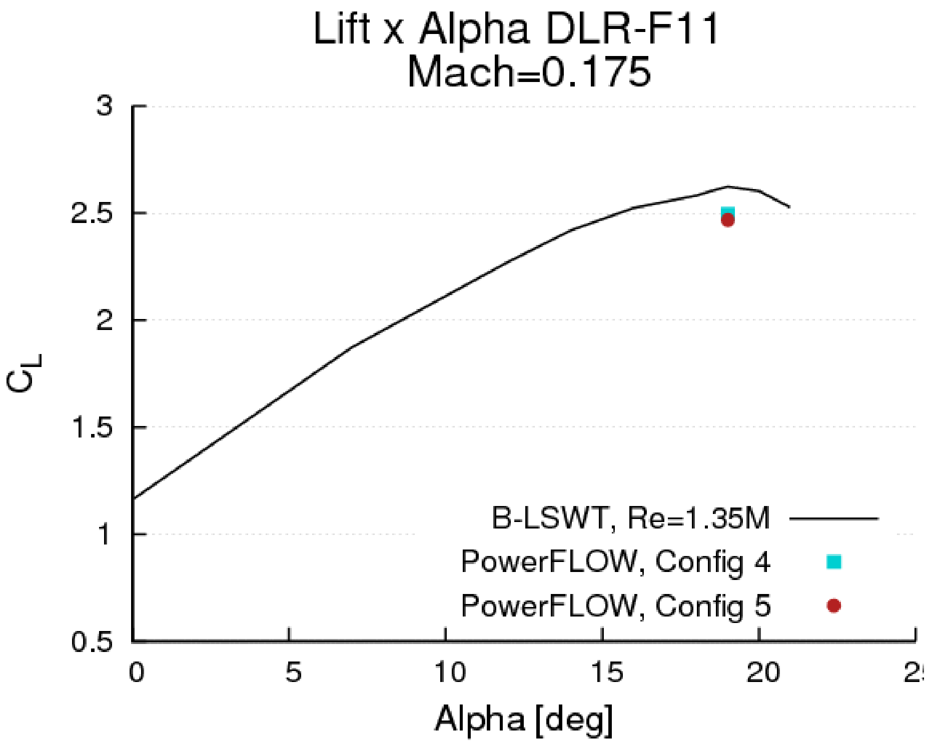


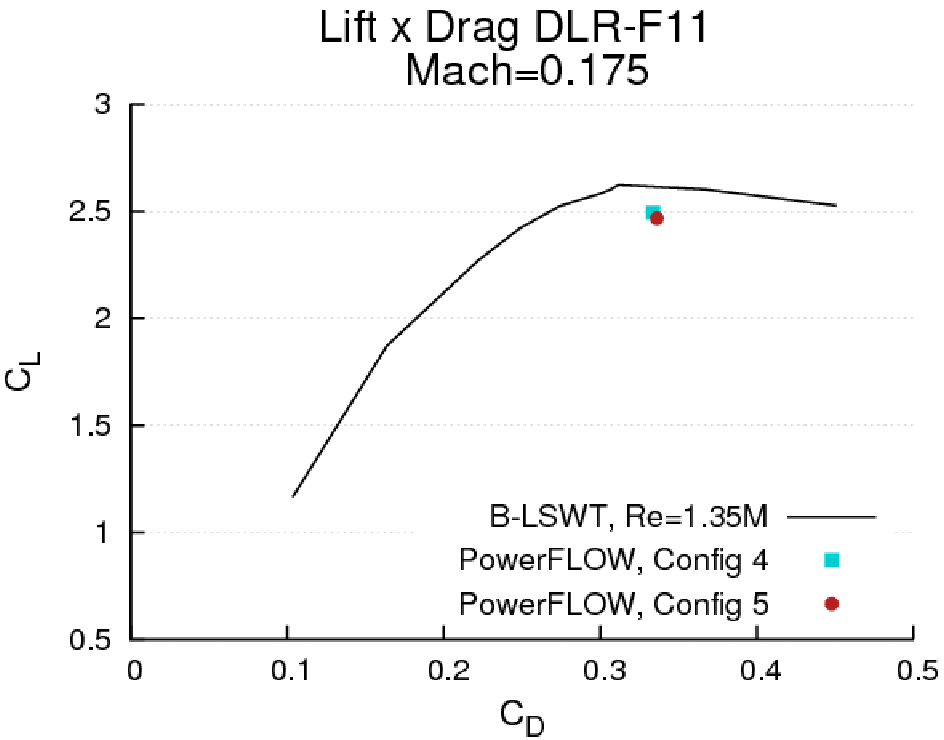


Comparison Config 4 vs Config 5

Results

Comparison Config 4 vs Config 5
Overview – Re = 1.35m



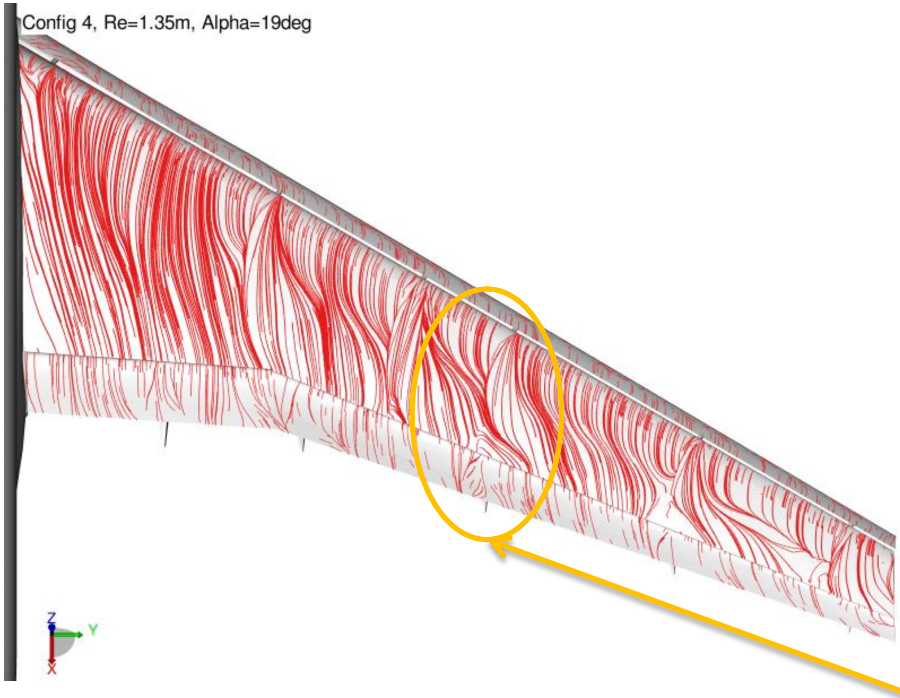


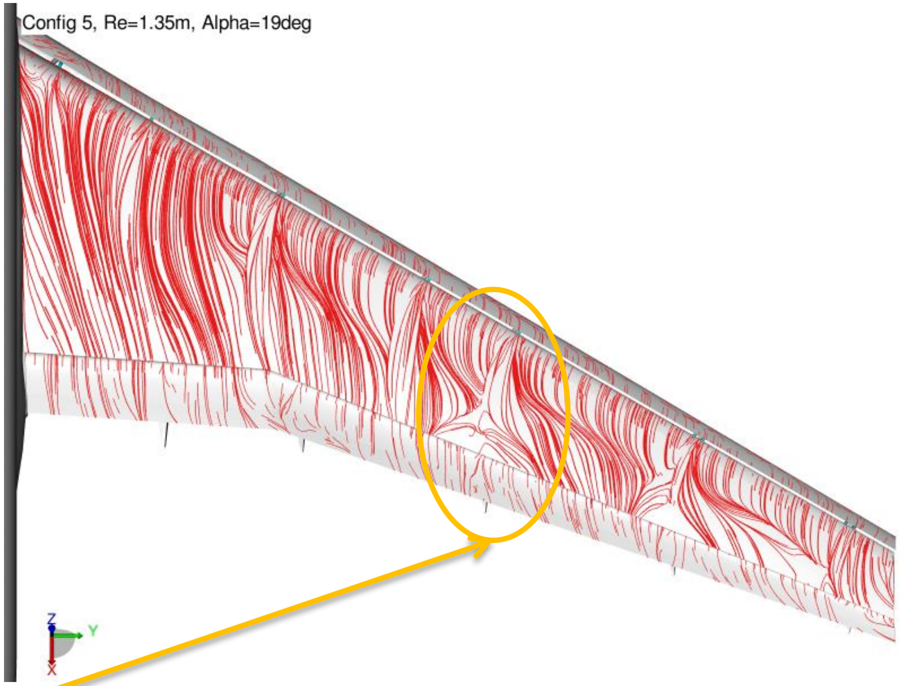
- Differences between Config 4 and 5 are smaller than overall differences to experiment
  →Should still be a valid comparison

Comparison Config 4 vs Config 5

Surface Stream Lines – Alpha = 19deg

Config 4	Config 5



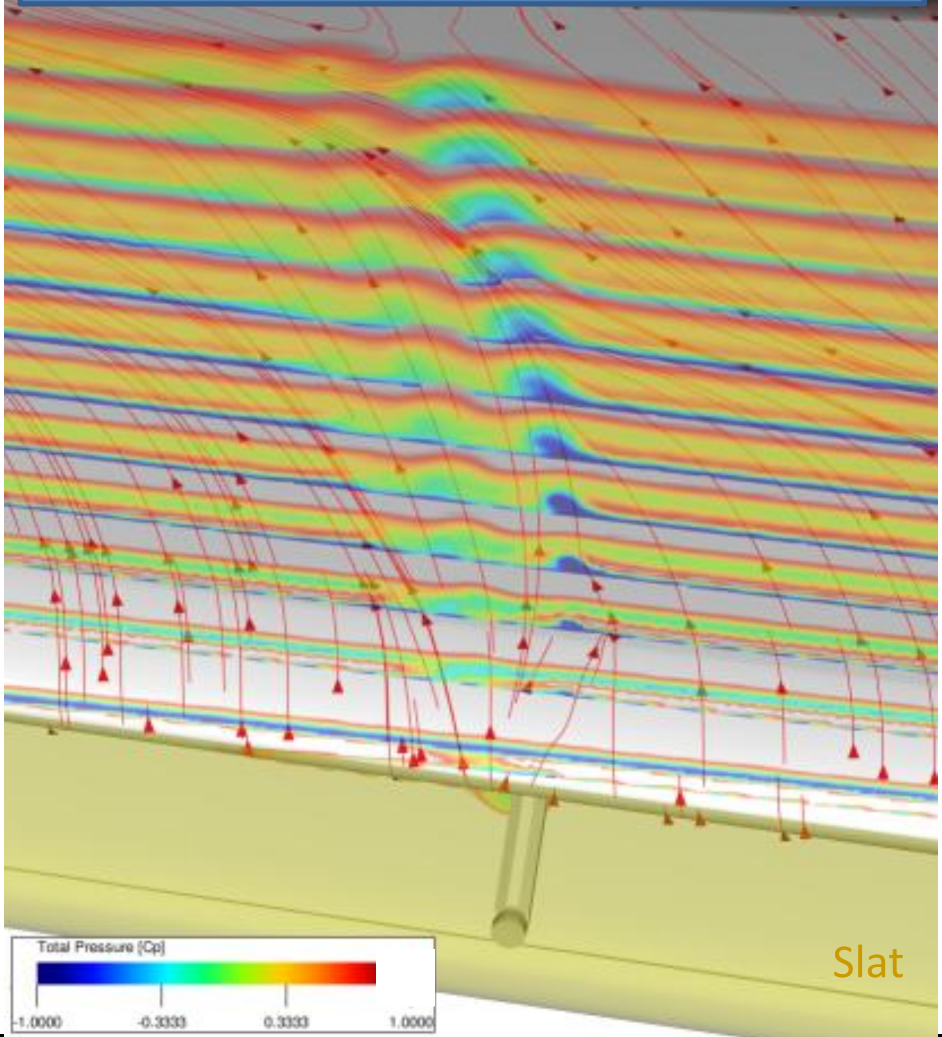


The flow separation driving the wing stall is missing on Config 4
→ Pressure tube bundles are crucial to predict stall correctly

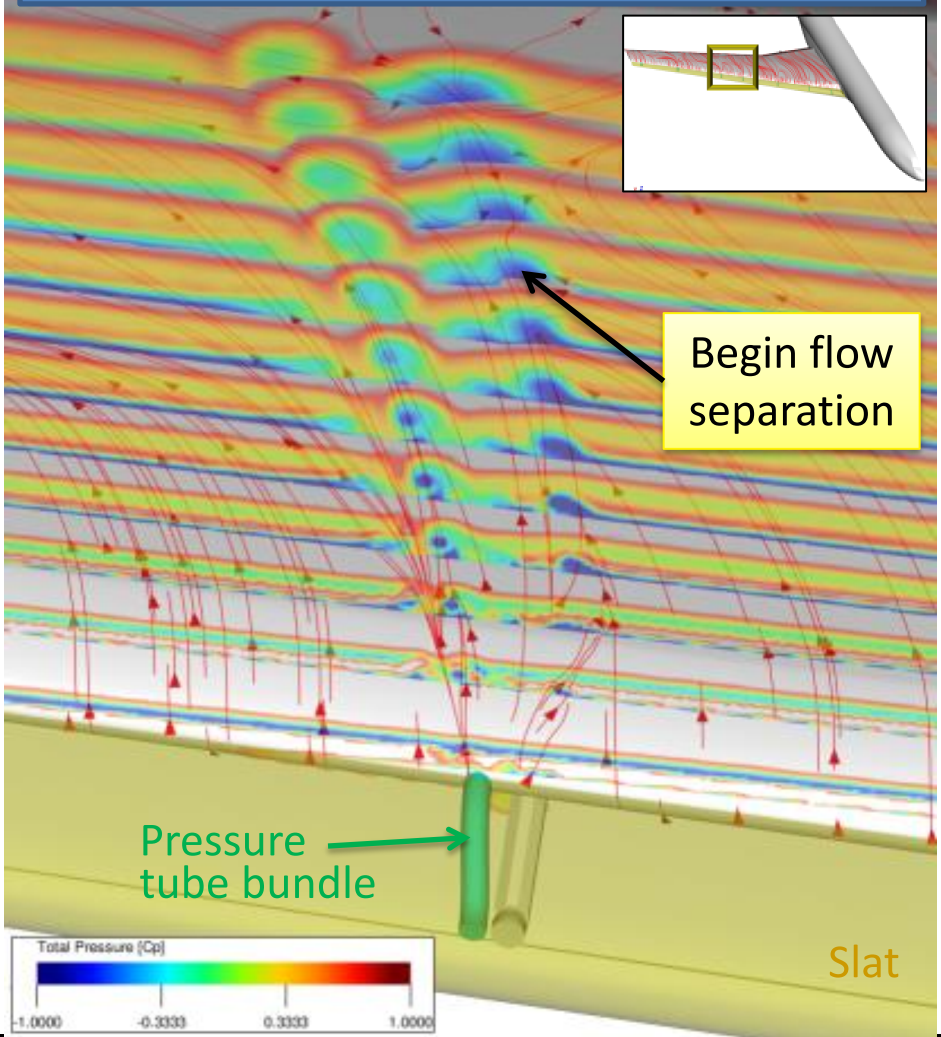
Comparison Config 4 vs Config 5

Total Pressure in the Stall Region – Alpha = 19deg

Config 4



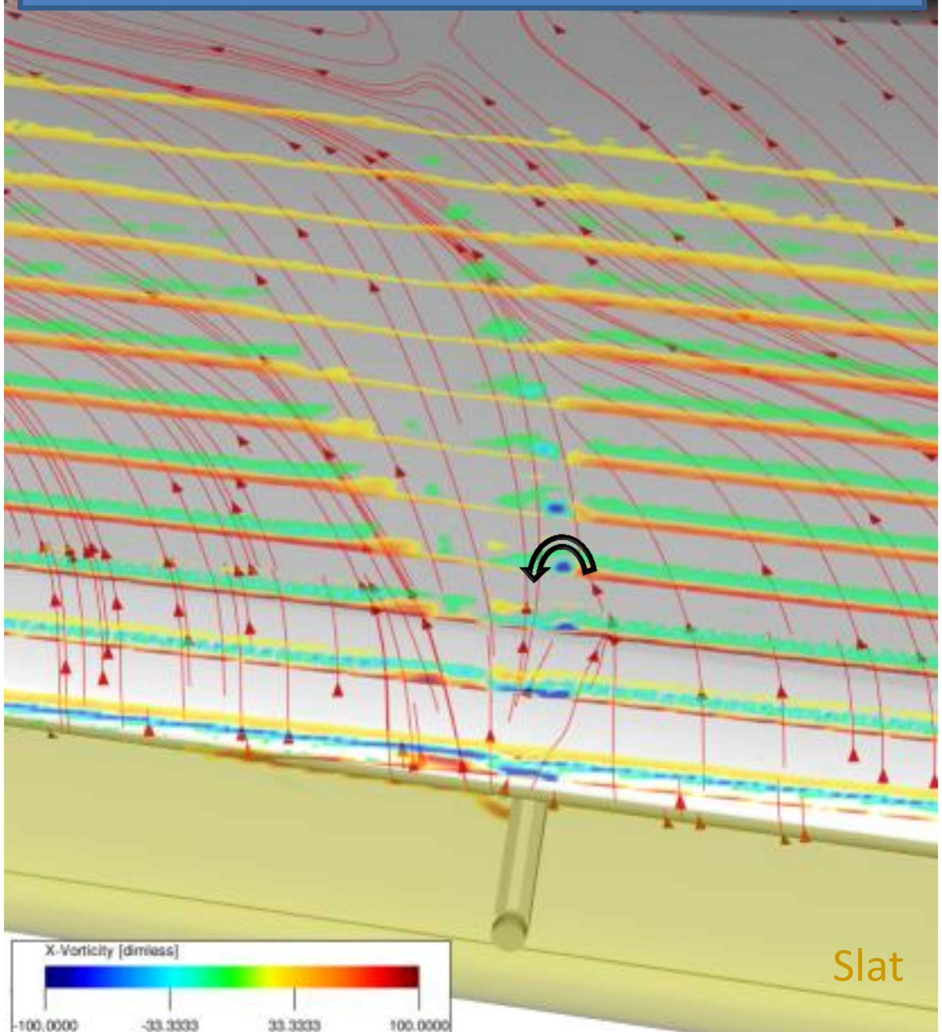
Config 5



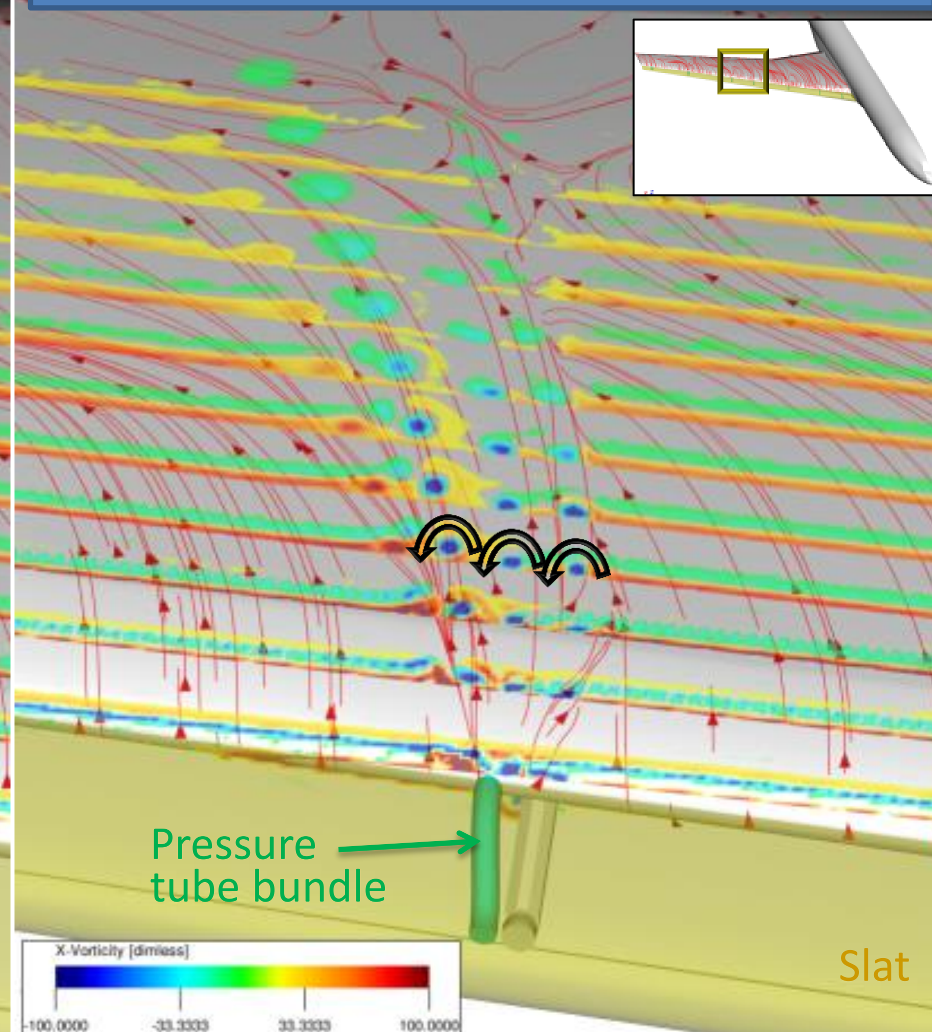
Comparison Config 4 vs Config 5

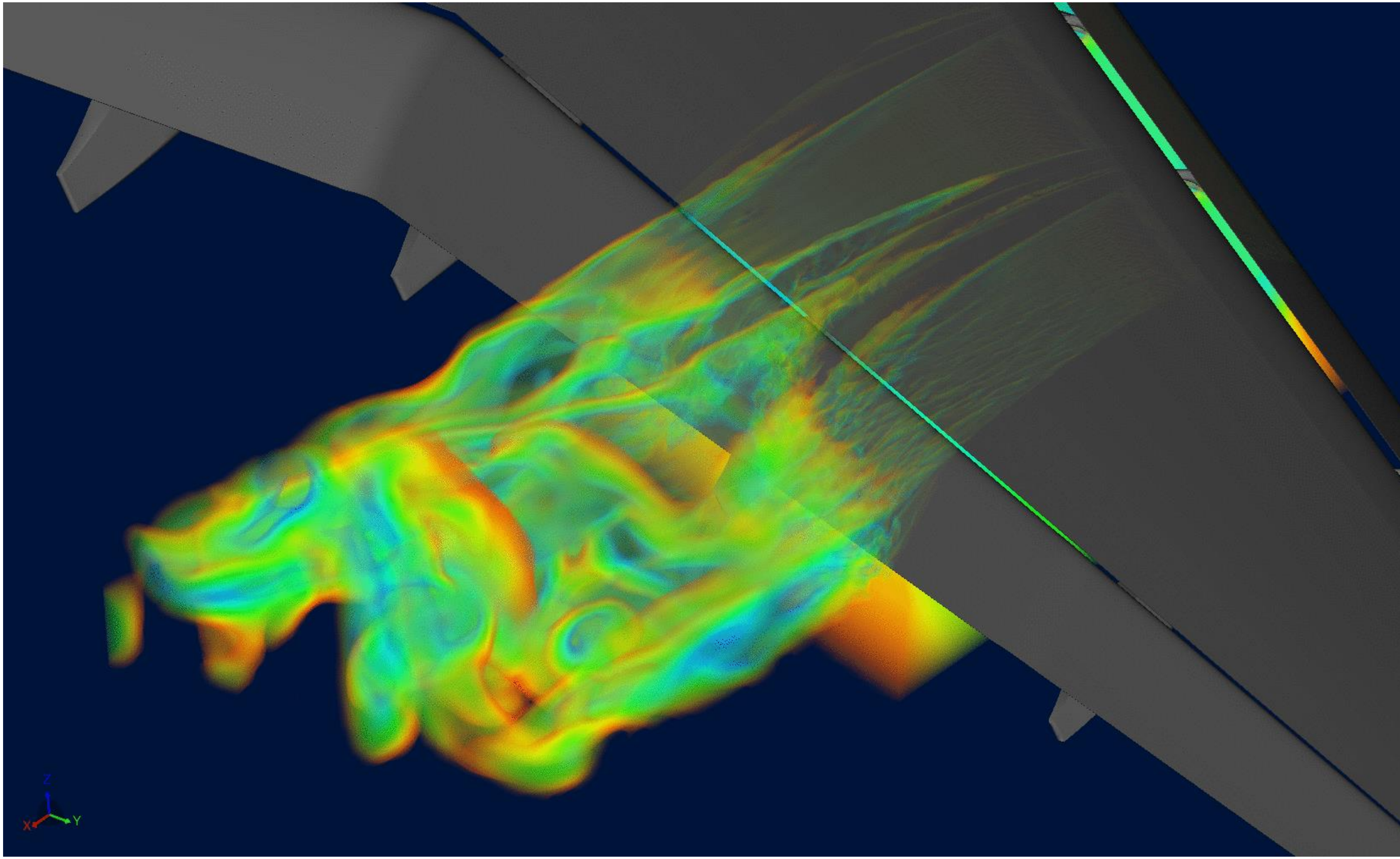
X-Vorticity in the Stall Region – Alpha = 19deg

Config 4



Config 5




Z
X
Y

Conclusions

- General
  - *Good agreement with experimental pressure distributions*
  - *Significant dependency on laminar/turbulent transition*
  - *Stall mechanism well predicted but separation too small*
    → stall delayed
- Resolution Study
  - *Reasonable grid convergence achieved for AoA=16deg*
    - impacted by unsteady flow
- Reynolds Study
  - *Reynolds Trends captured well*

Next Steps

- Run Grid Sensitivity Study at AoA=7deg
- Investigate dependency of stall on
  - *Laminar/turbulent transition*
- Investigate WT effects
  - *WT walls*
  - *Peniche*
- Optimize grids
  - *for low and high Reynolds numbers separately*

Acknowledgement

We are grateful for support in conduction the simulations from

- McGill University, Montreal, Canada
- Purdue University, West Lafayette, IN

Thank You!

Additional Slides

Consideration on Measured Polar Shape

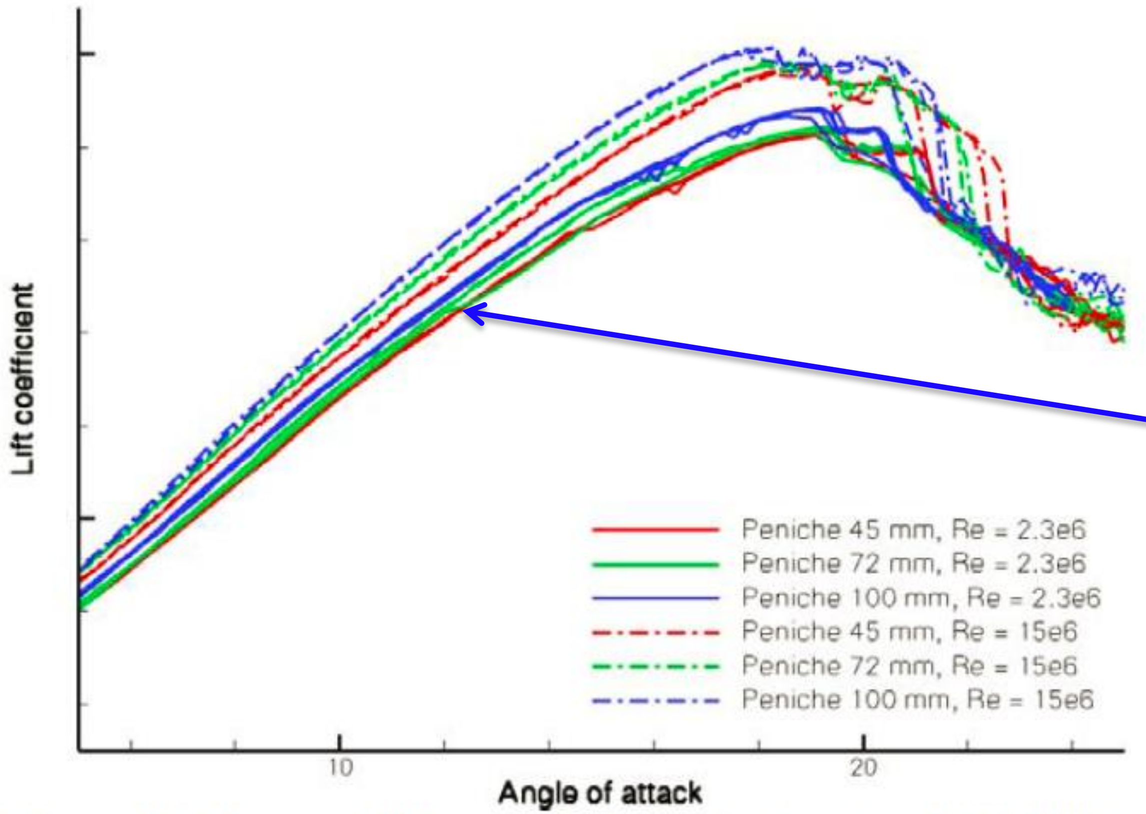


Figure 15: Measured lift curves for three different peniche heights

- Overall the peniche height has an influence, which can potentially not be fully corrected for
- Especially at lower Reynolds Numbers the polar shape can change due to the peniche

From: Application of Advanced CFD Tools for High Reynolds Number Testing,
S. Melber-Wilkending and G. Wichmann, DLR, AIAA 2009-0418